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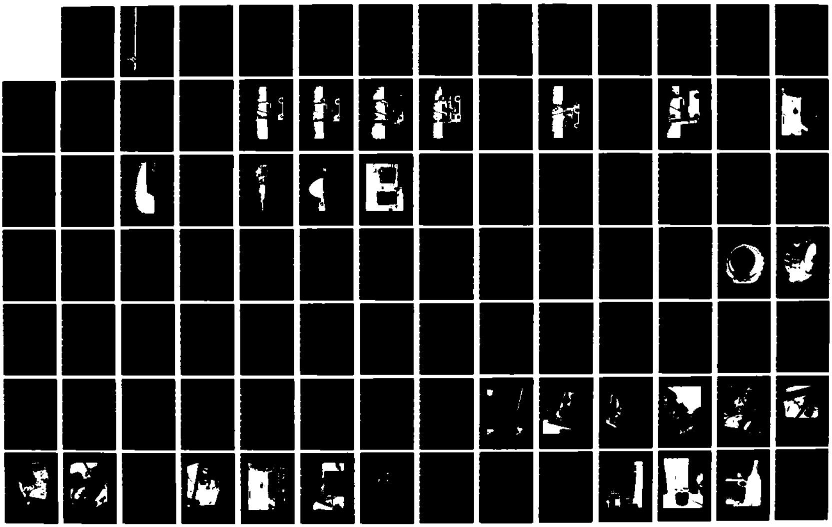

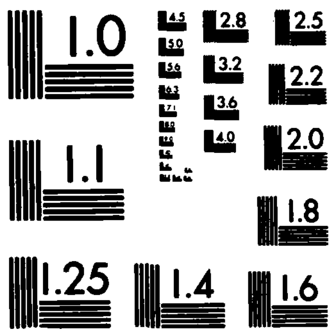

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Report 2369

AN INVESTIGATION OF THE COMMERCIAL ALTERNATIVE POWER SOURCES FOR THE COUNTERBALANCED INDUSTRIAL LIFT TRUCK

by

James E. Stephens, Jr.

and

Tim F. Lee

October 1982

U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Comparative analysis of four different power sources (gasoline, liquid petroleum gas (LPG), diesel, electric) for 4,000-lb capacity forklift trucks is presented for productivity, exhaust emission characteristics, noise levels, energy consumption, reliability, maintainability, operating costs, and safety ramifications.

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Principal Conclusions: 1. Internal combustion engine (ICE) trucks are more productive than are electric. 2. Diesel was most productive truck. 3. Electric truck was most economical considering only energy costs (diesel was second). 4. All trucks except electric exceeded accepted noise standard. 5. Diesel truck emitted significantly less carbon monoxide (CO) than did gasoline or LGP.

PREFACE

The counterbalanced industrial lift truck is recognized as the most versatile item of material-handling equipment. The majority, in both the commercial and Army fleet, are concentrated in the capacity range of 4000 to 6000 lb of lift. Within this capacity range, the user must select from among several alternative power sources for the lift truck including gasoline-engine-driven, liquid-petroleum-gas-engine-driven, battery-powered electric-motor-driven, and diesel-engine-driven. There are many factors which influence the user's decision, not the least of which is a significant volume of commercial literature claiming a particular power source alternative to be superior.

The power source alternative selected has significant implications especially to the military which typically operates a forklift 15 yr or longer before replacement. It is imperative that the correct power source alternative is selected for procurement. Therefore, MERADCOM, under Military Adaptation of Commercial Items (MACI) Project 3614, investigated the performance parameters of the alternative power sources. The results of the investigation are contained in this report.

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AN INVESTIGATION OF THE COMMERCIAL ALTERNATIVE POWER SOURCES FOR THE COUNTERBALANCED INDUSTRIAL LIFT TRUCK

I. INTRODUCTION

1. **Objective.** The purpose of this investigation is to determine the relative merits of the four alternative power sources for counterbalanced industrial lift trucks. As a minimum the following measures of performance will be evaluated:

a. Productivity.

b. Exhaust emissions.

c. Noise levels.

d. Energy consumption.

e. Reliability.

f. Maintainability.

g. Operating costs.

h. Safety ramifications.

The results of the analysis will be used to support the tradeoff process by which the alternative power source(s) most suitable to the military is selected.

2. **Background.** The Army's fleet of counterbalanced industrial lift trucks is comprised today of gasoline-engine-driven and battery-powered electric-motor-driven trucks. These lift trucks were procured using Military Adaptation of Commercial Items (MACI) specifications prepared by MERADCOM to reflect both the Army user's requirements and the commercial state-of-the-art. The gasoline-engine-powered trucks are used in general warehousing operations and predominantly (compared to electric-motor-driven) in outdoor operations. Electric-motor-driven trucks are used almost exclusively inside in general warehousing operations and are the only practical power source for use in hazardous operations, such as ammunition handling, or in controlled humidity food warehouses. The word practical relates to both the fact that only the electric-motor-driven lift truck is readily

available in the more stringent safety classifications and that it operates practically emission free. However, since hydrogen is released during charging, the battery must be charged at a facility designed to satisfy the many safety requirements and maintenance procedures associated with industrial lift truck batteries. One method of satisfying these requirements is a single centrally located charging facility which serves the entire civilian or military complex. Generally, the lift truck is driven to this central charging facility where its battery is either exchanged for a charged one or the lift truck is parked at the charging station while its battery is charged. An alternative to driving the lift truck to the central charging facility is a battery exchange truck used to supply charged batteries to the lift trucks at their individual work stations. Delivering batteries or driving vehicles to a central charging facility, at least at military ammunition depots, can be a significant logistical burden, as lift trucks are dispersed over a wide area.

The design of the electric lift truck has been optimized for use on a hard, level surface with travel distances kept to a minimum. As the actual conditions deteriorate from this optimum, productivity of the electric lift truck declines because the power demanded for travel shortens battery life between charges to an unacceptable level. Consequently, at military ammunition depots, one observes the use of two lift trucks working in concert where a single lift truck would normally be sufficient. One of the two lift trucks will be electric-motor-driven to satisfy safety requirements. It is used inside the magazine or igloo to move ammunition to the doorway; then, the second truck, a pneumatic-tired, internal-combustion-engine-powered lift truck (gas-,diesel-,or LPG-engine driven) is used to complete the necessary handling operation on the hardstand or unimproved surface outside of the igloo or magazine. Operating in this manner, the battery life between charges is prolonged by eliminating the requirement for an electric truck to work on slopes, ramps, and unimproved surfaces.

The obvious solution to the recharging problem is to use the internal-combustion-engine-powered lift truck for all tasks in the mission. However, Army safety regulations have prescribed the use of electric-powered MHE to handle ammunition in igloos and magazines. These regulations have their origin in the concern for safe handling of explosives in an enclosed area rather than a concern for the environmental quality in which personnel must function. However, in general warehousing operations, there is increasing concern for the environmental effects of exhaust and noise pollutants and the ability of warehousing operations to meet OSHA standards. This concern for environmental quality is shared by both industrial and military complexes where powered MHE is used, but how it is best accomplished is tempered by a desire for productivity and cost effectiveness. The variable most basic for a balance of environmental quality, productivity, and cost effectiveness is the MHE's power source type. In addition, other growing concerns are the availability of petroleum as an energy source and energy conservation. All of these things must be considered when the lift truck power source type is selected.

Four power source types for lift trucks are recognized: battery-powered electric-motor-driven, gasoline-engine-driven, LPG-engine-driven and diesel-engine-driven. It is important to understand the significance to the military of the power source type selected. First converting from one power source to another after purchase is impractical with the exception of the widely practiced gasoline to LPG conversion. A recent survey of lift truck manufacturers found that "Of the Internal Combustion Engine (ICE) trucks produced, 35 percent to 50 percent are LPG-powered; 50 percent of delivered trucks are converted to LPG in the field."[1] Not only is converting from one power source type to another impractical except as noted above, but the Army's replacement cycle for lift trucks is 11 years for ICE (gasoline, diesel, and LPG) and 18 years for electric-motor-driven.[2] Therefore, once the power source type is selected, at least for the Army, it is not only impractical to convert to another type (except as noted) but the Army must live for many years with the total impact of that selection. The only practical opportunity for the Army to select an alternative power source type occurs when new lift trucks are procured. The decision-making process to properly exploit this opportunity must be supported by an objective analysis of the relative merits of the four power source types. A source of empirical data for this objective analysis could not be found. Rather, numerous analyses by commercial manufacturers were reviewed which purported that their power source type was superior to another. However, without charging bias, the analysis tended to highlight only one concern such as energy savings and excluded all others. As an example, one analysis was reviewed which examined annual energy costs savings while omitting any discussion of productivity of the various power source types. To fill this data gap MERADCOM designed a test program to support an objective analysis power source type versus the concerns previously discussed. The test program was designed from the perspective of an MHE user faced with the problem of selecting the best alternative for their application from among the four alternative power source types indentified above.

The test was divided into three dis[illegible]t phases: (1) Acquiring the lift trucks with the power source type to be investigated; (2) acquiring data via field test; (3) analysis of data. Each of these phases will now be discussed.

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1 Root, Linwood C., "FORKLIFT TRUCK, GASOLINE-ENGINE DRIVEN, 4000-POUND-CAPACITY, PNEUMATIC-TIRED, 72-INCH COLLAPSED MAST HEIGHT, 144-INCH LIFT HEIGHT–MANUFACTURER SURVEY." U.S. Army MERADCOM Report No. 2243, May 1978, Page 7.

2 TB-43-0002-24-1980.

II. INVESTIGATION

3. **Acquisition of Lift Trucks for Test.** Six lift trucks for test were acquired from three different sources. All of the trucks were rated commercially at 4000-lb capacity at a 24-in. load center and 180-in. lift height capability and were equipped with solid rubber tires. Two of the six trucks were drawn from Army inventory, the first to be the baseline gasoline-engine-powered lift truck and the second for converting to LPG-engine-powered. Both were manufactured by Allis-Chalmers under contract DSA 700-74-C-9020 (NSN 3939-00-556-4955). They were issued new with zero hours to MERADCOM. These trucks were procured using the military quantity procurement process which cited MACI Specification MIL-T-52962 as the performance requirement for these trucks. Figure 1 provides a view of the baseline truck from contract DSA 9020 evaluated in this test program. This gasoline-engine-powered baseline truck will be referred to in the remainder of this report as No. 94, and the baseline lift truck converted to LPG engine as part of the test program will be referred to as No. 95 (Figure 1A). Three of the remaining lift trucks, one each battery-powered electric-motor-driven, gasoline-engine-driven, and LPG-engine-driven, were competitively procured from Allis-Chalmers using a purchase description prepared by MERADCOM. Three manufacturers, Allis-Chalmers, Caterpillar, and Hyster, responded to MERADCOM's request for proposal. Allis-Chalmers was the successful bidder and delivered the three lift trucks to MERADCOM for test. The Allis-Chalmers commercial gasoline-engine-powered lift truck purchased by MERADCOM for this lift truck test is shown in Figure 2 and will be referred to as No. 92. The Allis-Chalmers commercial LPG-engine-powered lift truck is shown in Figure 3 and will be referred to as No. 91. Table 1 compares the salient features of No. 91 and No. 92. The commercial battery-powered electric-motor-driven lift truck is shown in Figure 4 and will be referred to as No. 103.

The five lift trucks discussed to this point were manufactured by Allis-Chalmers and therefore share many components in common. As an example, the mast assemblies and tires are interchangeable. Table 1 portrays that a significant degree of commonality exists between all the lift trucks tested from Allis-Chalmers. Obtaining one of each power source type from the same manufacturer supported the test objective of evaluating the relative merits of the power source. By choosing lift trucks for test from the same manufacturer, the assumption was made that the lift trucks would share the same design criteria thereby allowing one to examine more accurately the differences attributed to the power source itself. MERADCOM's attempt to procure a diesel-engine-driven lift truck in a solid-rubber-tired model 4000-lb-capacity model from Allis-Chalmers was unsuccessful as they did not offer this truck commercially.

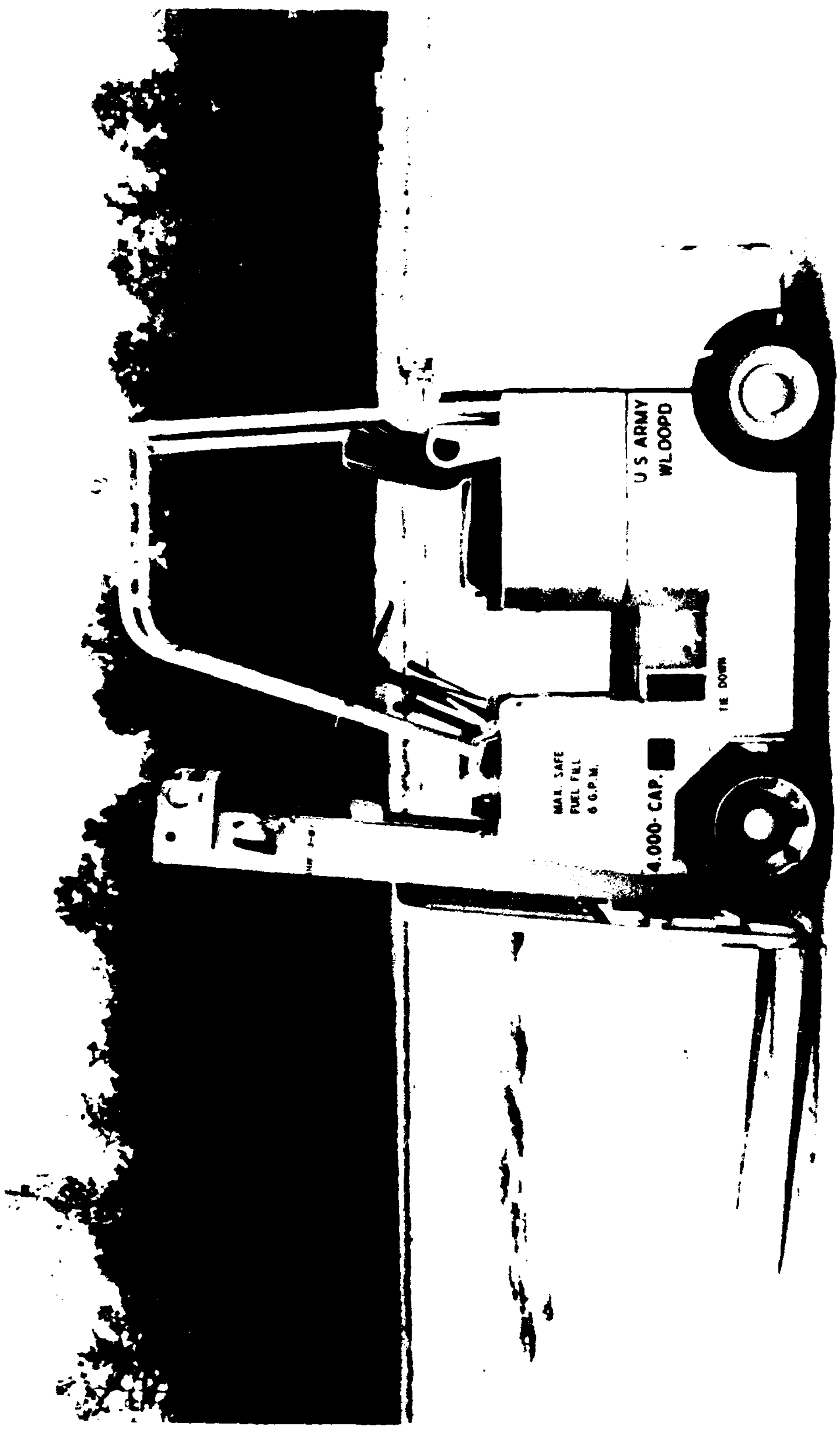


Figure 1. MIL SPEC GED SRT (gasoline), no. 94.

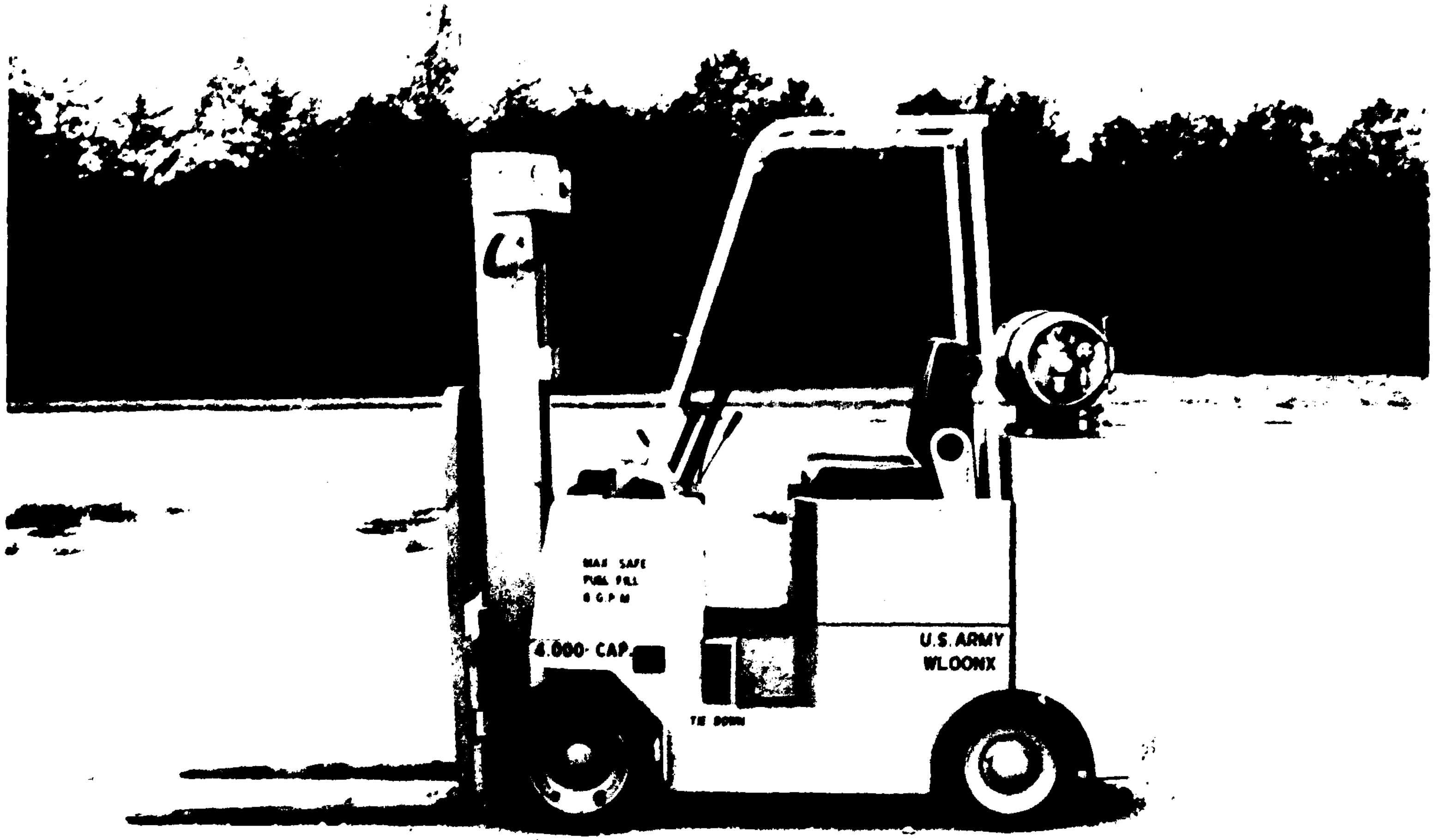


Figure 1A. MIL SPEC GED SRT, converted to LPG, no. 95.

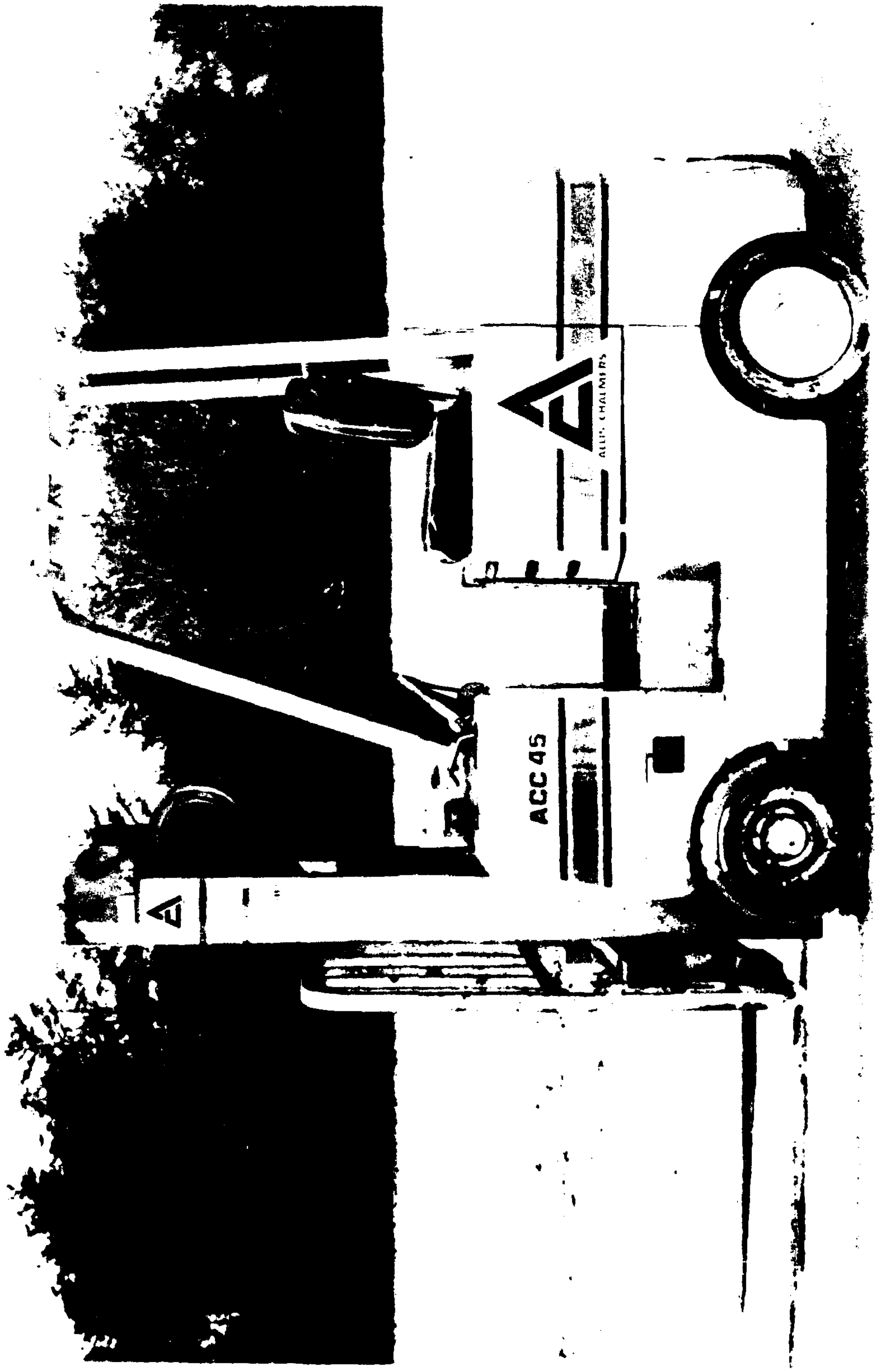


Figure 2. Allis-Chalmers ACC 45 (gasoline), no. 92.

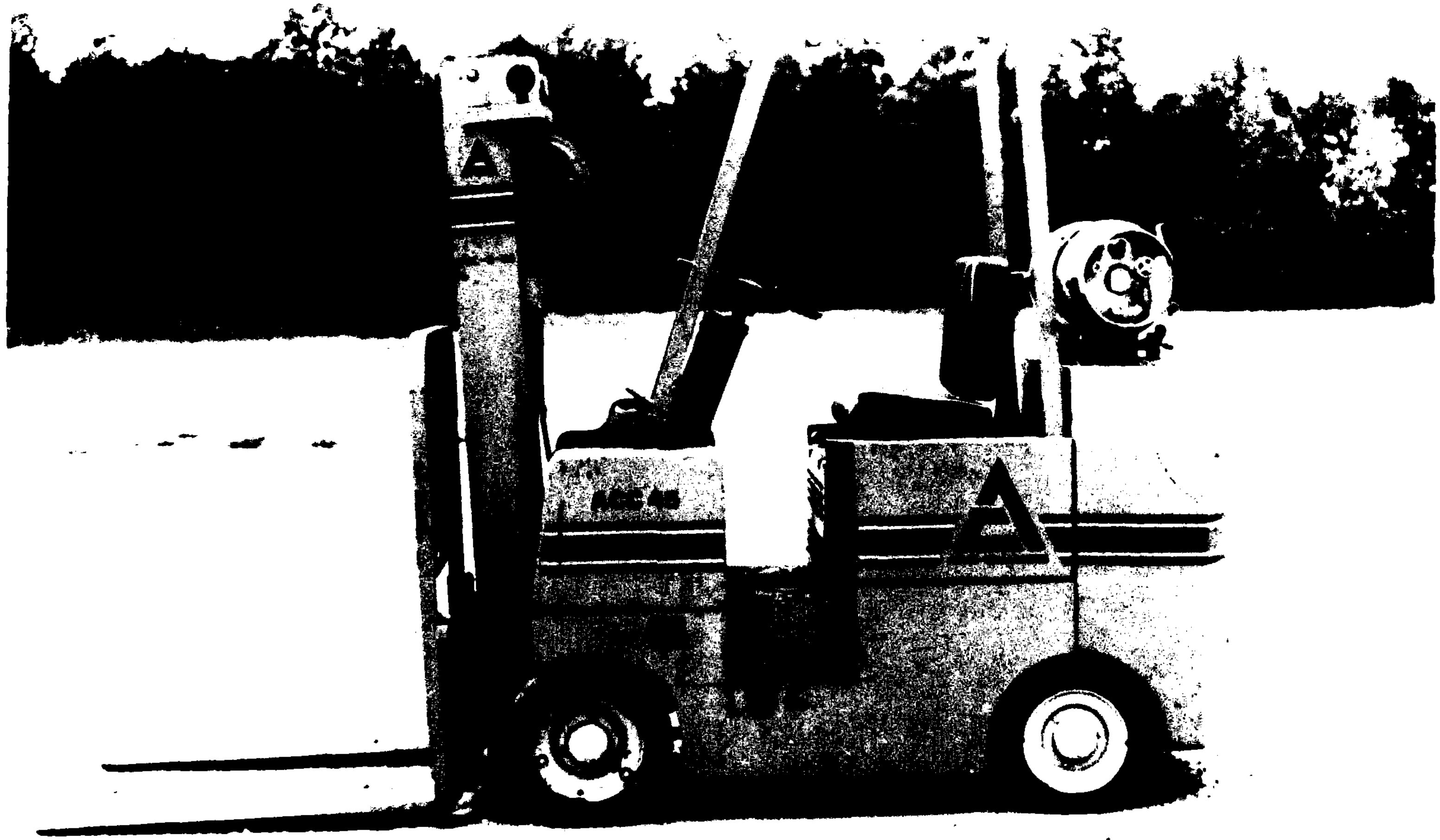


Figure 3. Allis-Chalmers ACC 45 (LPG) gravel, no. 91.

Table 1. Comparison of Power Source Test Truck Features

	Test Truck No.					
	91	92	94	95	103	106
Manufacturer	Allis-Chalmers	Allis-Chalmers	Allis-Chalmers	Allis-Chalmers	Allis-Chalmers	Hyster
Contract No.	9020	0045	9020	0045	0045	
Truck Model No.	ACC40	ACC45	ACC40	ACC45L	ACE40	S50E
Truck Weight (lb)	6696	8020	7980	8020	6222	8850
Engine or Drive Motor Manufacturer	Continental	Continental	Continental	Continental	Siemens Allis	Perkins
Engine (motor) Model No.	F135	F163	F135	F163	725D28V	4-154
Engine Displacement (in.^{3})	135	162	135	162	NA	154
Fuel Type	LPG	Gasoline	Gasoline	LPG	Electric	Diesel
Fuel Tank Capacity	33 lb	6.5 gal	6.5 gal	33 lb	NA	10 gal
Industrial Battery Voltage	NA	NA	NA	NA	36	NA
Battery Amp-hr Rating	NA	NA	NA	NA	850/6 h	NA
Battery Weight (lb)	NA	NA	NA	NA	2685	NA
Lift Height (in.)	180	180	180	180	180	184
Collapsed Mast Height (in.)	79	79	79	79	79	82.5
Free Lift (in.)	63	63	63	63	63	64.5
Load Capacity (lb)	4000	4000	4000	4000	4000	4000
Load Center (in.)	24	24	24	24	24	24
Forward Tilt Angle (°)	5	5	6	6	5	6
Rearward Tilt Angle (°)	4	4	2	2	2	4
Sideshift (in.)	4	4	NA	NA	4	4
Wheelbase (in.)	50	50	50	50	48	51.5
Truck Width (in.)	38	38	38	38	40	41
Tire Size — Front	18x8x12	18x8x12	18x9x12	18x9x12	18x8x12	18x9x12
Rear	16x5x11	16x5x11	16x5x11	16x5x11	15x5x10	16x6x10

Figure 4. Allis-Chalmers ACC 45 (electric), no. 103.

Therefore, a sole source contract was awarded to Hyster for a commercial diesel-engine-driven solid-rubber-tired lift truck. Hyster was found to be the only manufacturer offering such a truck commercially although other manufacturers now brochure this truck. This truck is shown in Figure 5 and will be referred to as No. 106.

Table 1 presents the salient characteristics of the lift trucks evaluated in this test.

4. **Acquisition of Industrial Lift Truck Battery**. Lift truck No. 103 was supplied with one industrial lift truck battery. A second battery was required to expeditiously conduct the test. Therefore, the decision was made to purchase a second battery of the identical make and model to that supplied with lift truck No. 103. Table 2 gives the characteristics of the test batteries as well as the cost of the one purchased for test. Prior to test use, each battery was cycled a minimum of three times. Cycling consisted of discharging the battery 80 percent of its capacity and recharging the battery in accordance with the manufacturer's instructions.

5. **Acquisition of LPG Conversion Kit**. The objective to acquire the kit competitively was not satisfied. The selected vendor provided a kit which could not be successfully mounted on lift truck No. 95. The vendor had supplied his standard kit which converts Allis-Chalmers commercial model ACC 45 PS lift truck to LPG. However, the lift truck being converted at MERADCOM, although designated as Allis-Chalmers Model ACC 45 PS, is equipped with a 135-in.^{3} engine supplied in the commercial Allis-Chalmers Model ACC 45 PS lift truck. The vendor's mistake occurred even though the Government's requisition correctly cited both lift truck and engine make and model. The vendor did not offer a standard kit for the smaller engine in No. 95. Allis-Chalmers was found to list a kit for converting a No. 94 type lift truck to an LPG-powered lift truck. This kit was then obtained from the local Allis-Chalmers dealer. The engine compartment of No. 95 with the LPG conversion kit installed is shown in Figure 6. The kit was installed by two mechanics and a technician initially as a mockup to supplement the minimal instructions provided in the kit. With this initial mockup and using the supplemented instructions, one mechanic retrofitted No. 95 from gas- to LPG-engine-powered in 2 manhours. Appendix C documents the complete process of converting No. 95 to LPG-engine-powered.

6. **Test Procedures**. The Field Test Branch of MERADCOM's Product Assurance and Testing (PA&T) Directorate conducted the field test in accordance with test guidelines prepared by the Mechanical Equipment Engineering Division and coordinated with the PA&T Directorate. These test guidelines as presented to the Field Test Branch can be reviewed in Appendix B.

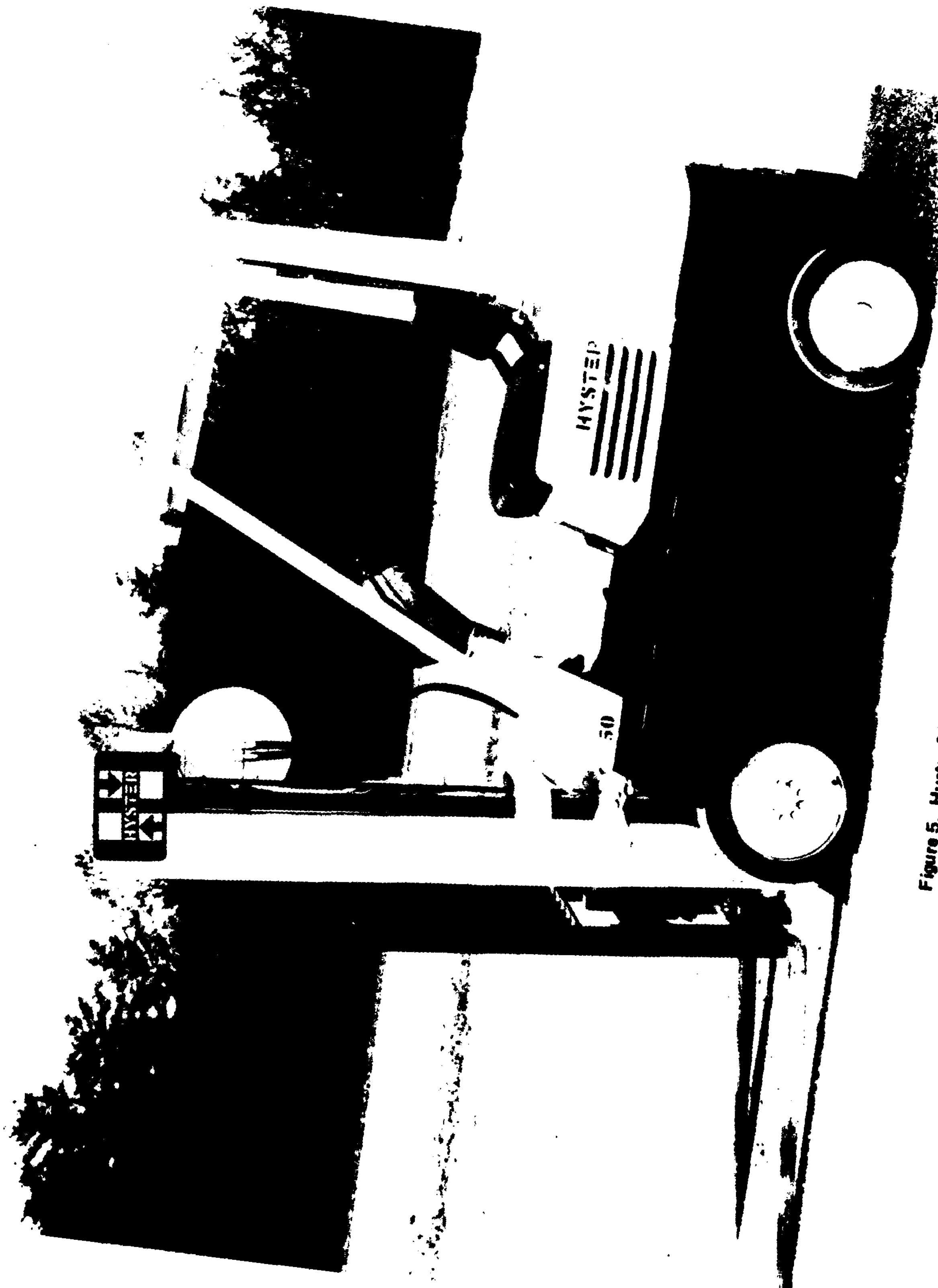


Figure 5. Hyster S40E (diesel), no. 106.

Table 2. Characteristics of Truck Battery, Battery Charger, and Kilowatt-Hourmeter

	Characteristics
Truck Battery:	Voltage: 36 Type: Lead-Acid No. Cells: 18 No. Plates: 21 A/h Rating: 850/6 h Dimensions (in.): 39x25x23 Cost: $3285.00
Charger:	Manufacturer: Berg and Gibson Model No.: D68-1218-CSN Input: 230V/a.c./3 Phase; 25/15 A — 60 c Output: 36V/d.c.; 200 A
Kilowatt Hourmeter:	Manufacturer: Sangamo Weston Type: S55

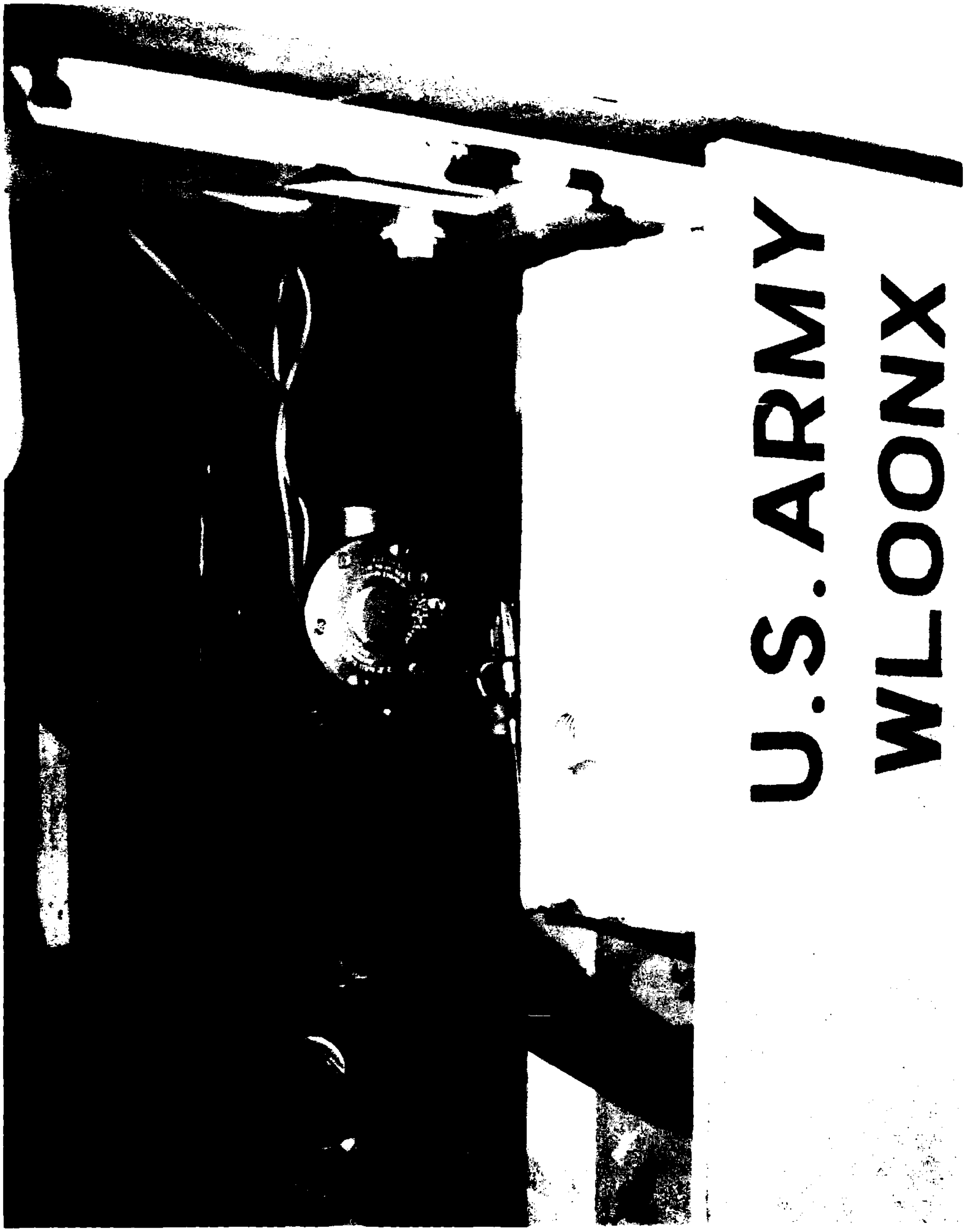


Figure 6. Gasoline engine converted to LPG.

Each lift truck was tested for a total of 280 h of which 200 h were accumulated by operating on MERADCOM's test track layout which conforms to MIL-STD-268C. This course layout was developed by the military as a test scenario to simulate the mission profile of Army lift trucks. All lift trucks purchased by the Army prior to the advent of commercial specifications in 1977 were required to successfully operate on this course for a period of time exceeding 200 h. Figure 7 and Figure 8 present the 200-h course layout which will be referred to as Course A. Each truck was also operated 40 h outside on a test course corresponding to Figure 9 laid out on concrete. Figure 10 presents a view of the concrete course which will be referred to as Course C. An additional 40 h were accumulated on a test layout except for a gravel base identical to the layout used for the 40-h concrete-based course. Figure 11 presents a view of the gravel course which will be referred to as Course G.

Data were manually recorded from all tests on Courses A, C, and G. The cycle times were recorded only from test on Course A. With this exception, data were collected in the identical manner on all courses. The field data collected included the clockhour and engine hourmeter readings at the start of each individual driver's shift. Whenever drivers were shifted, the clockhour the previous driver left was noted as well as the name of the new driver and the clockhour starting the shift. The engine hourmeter reading was also noted whenever fuel, LPG cannisters, or a charged battery were added. The appropriate entry for the type of power source was also made for energy consumed during the engine-hourmeter period in which the energy was actually consumed. The units of measure used for diesel and gasoline fuel was liters, for LPG–pounds, and for electricity–kWh. Gasoline and diesel fuel was provided by the Field Test Branch from their storage tanks. The diesel fuel was DF2 conforming to Fed Spec VV-F-800C. A complete analysis of the diesel fuel used during test is given in Appendix G. The gasoline was regular, unleaded with an octane of at least 87. LPG was purchased in 33-lb refillable cannisters by Government requisition from a local supplier. The supplier stated that the LPG as supplied conformed to HD-5 for LPG. The electric energy consumption was measured by a watthour meter placed in line before the charger. In this manner, the total energy consumed by both the charger and lift truck No. 103 was measured. A view of the battery charger is shown in Figure 12. As noted earlier, both batteries were cycled three times before actual test for record. Once test for record commenced, lift truck No. 103's battery was not exchanged for a charged one until the battery being used was discharged to the point where the high lift function could not be completed. However, this method caused initial problems with overheated electric motors and the batteries for the remainder of the test were exchanged at the end of 50 c for a recharged battery. At 50 c the lift cycle had slowed significantly and electric motor overheating was assumed to be incipient. Using this procedure, the batteries were discharged to 1.143 specific gravity average (Range 1.125 to 1.270) and recharged to 1.266 specific gravity average (Range 1.225 to 1.272). The discharged batteries were charged for 8 h at 36 Vd.c. Cells were randomly read for specific gravity and distilled water was added as required. No other maintenance to the batteries was required.

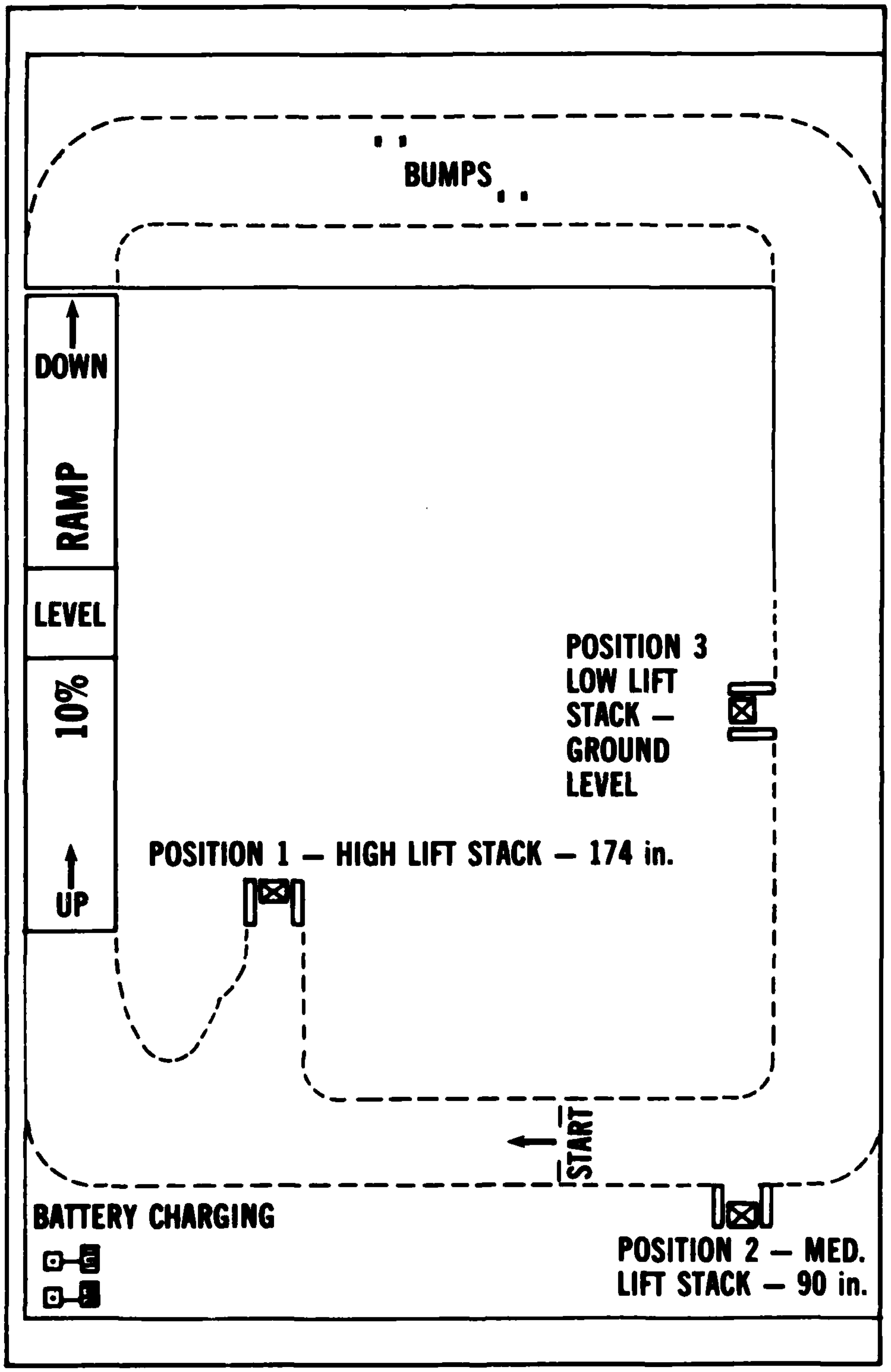


Figure 7. Materials-handling equipment test course.

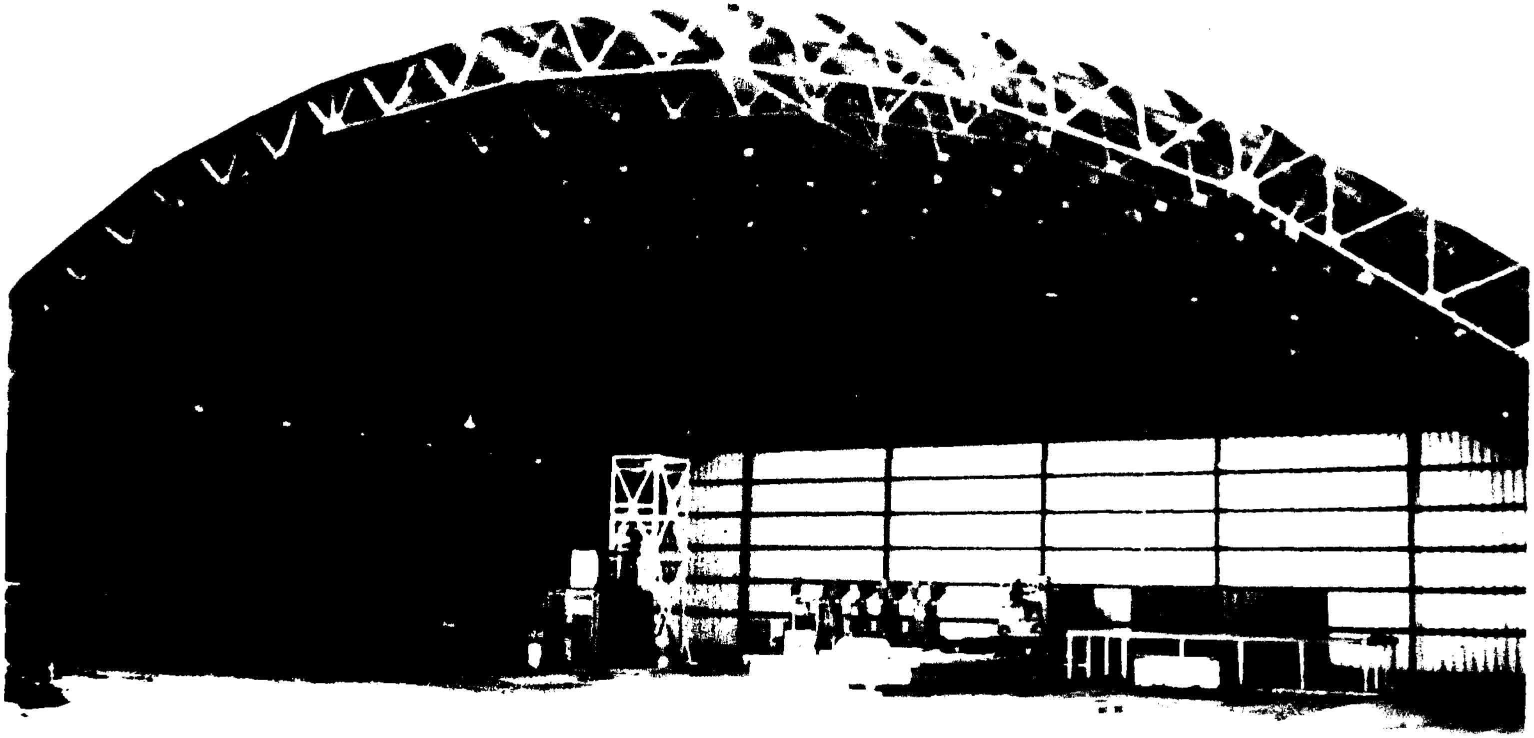


Figure 8. MERADCOM HME test facility; 200-h course (A).

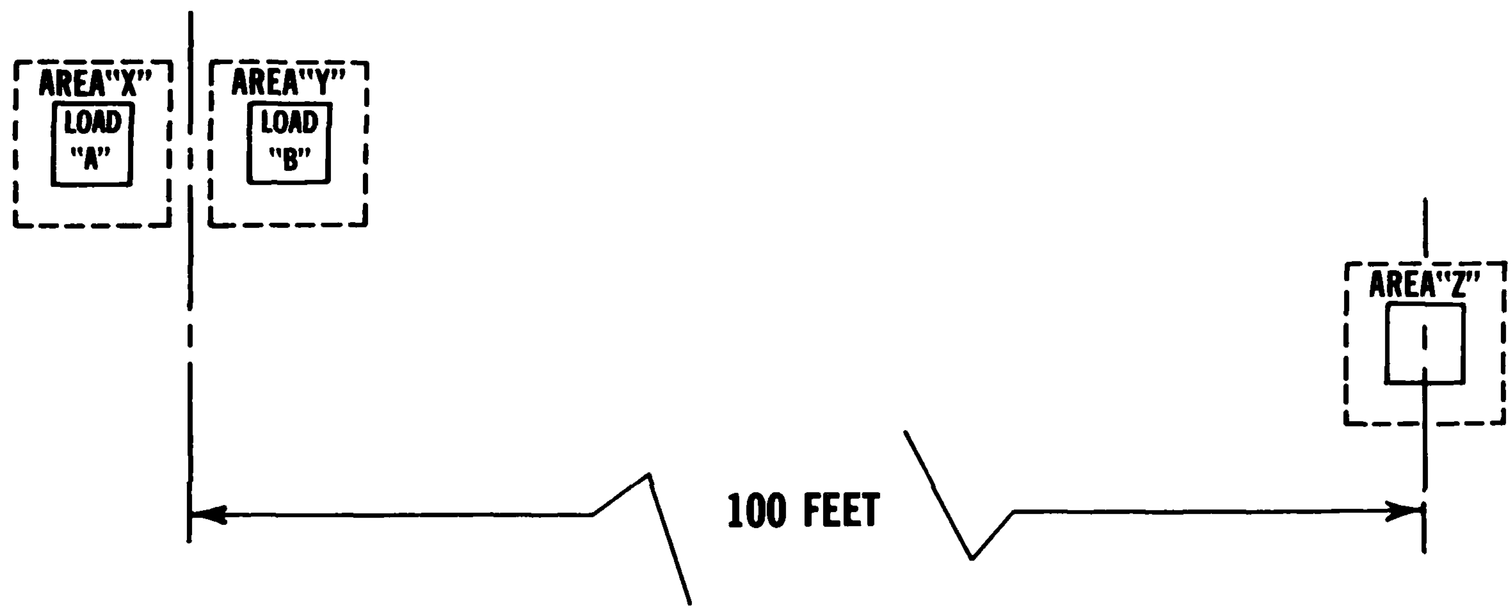


Figure 9. Test course (80-h).

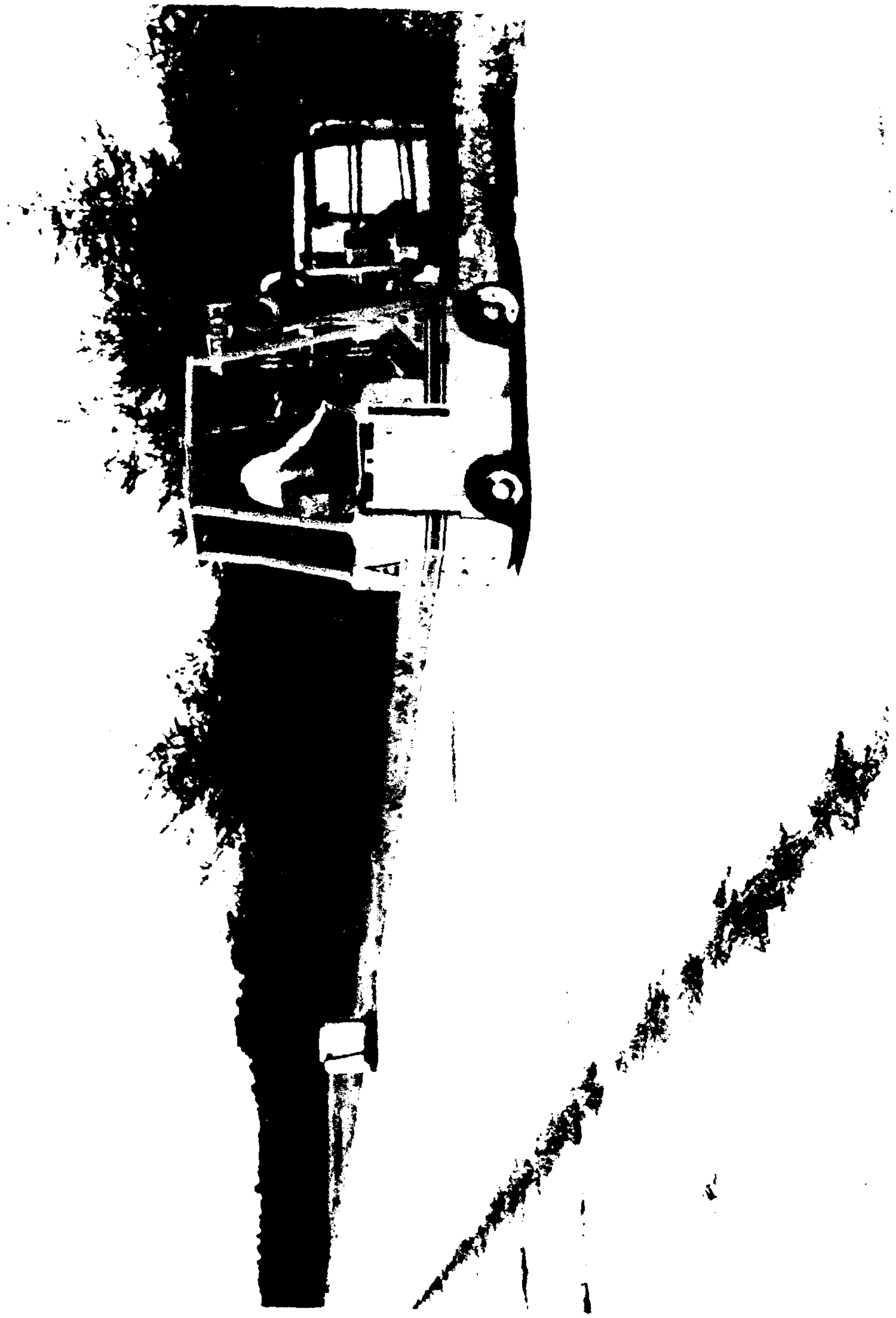


Figure 10. Concrete course (C).

Figure 11. Gravel course (G).

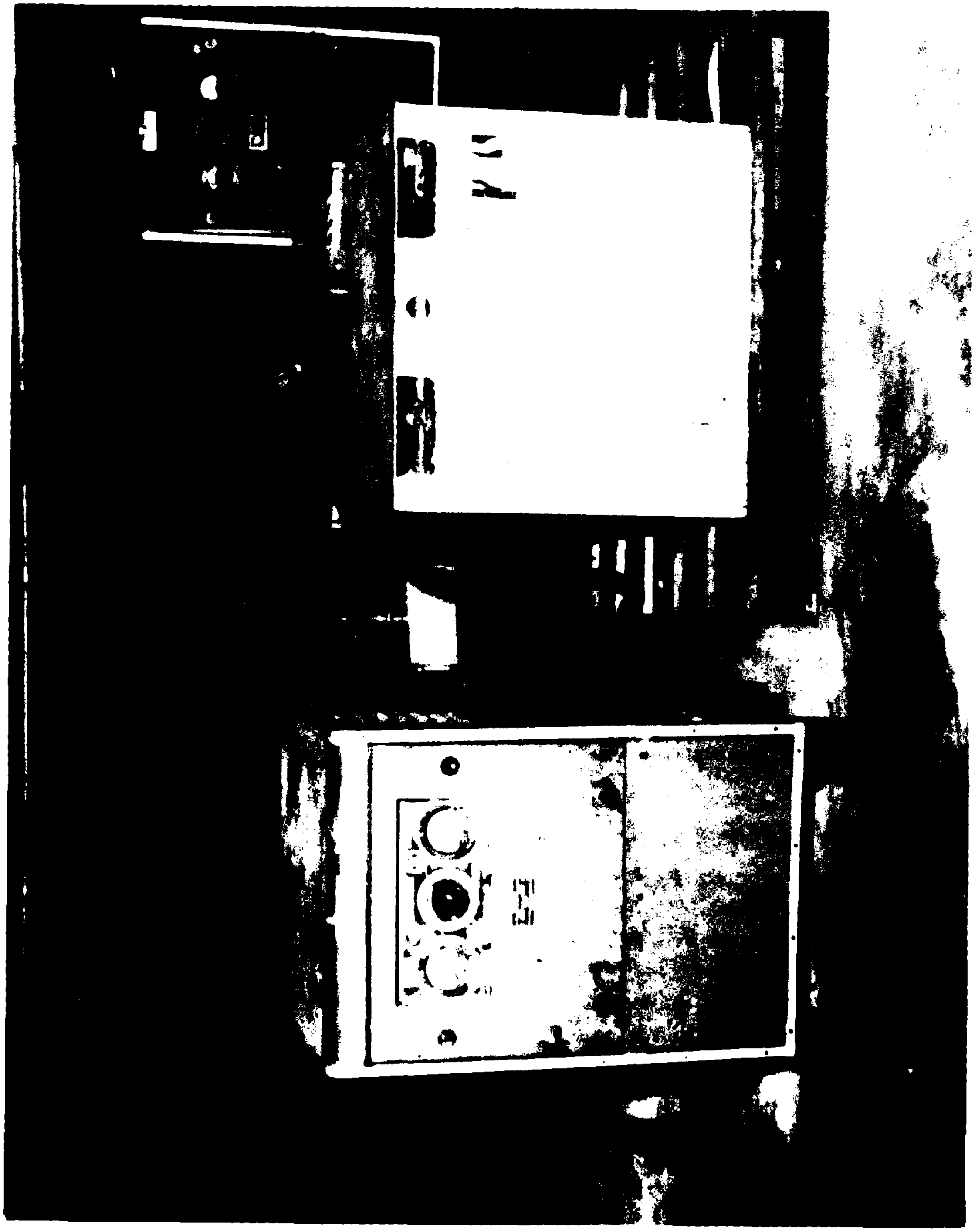


Figure 12. Battery changing station.

Preventive maintenance was performed on all lift trucks in accordance with the manufacturer's service manual for No. 91, No. 92, No. 103, and No. 106 and in accordance with the Army Technical Manual for No. 94 and No. 95. The LPG kit installed on No. 95 was serviced in accordance with the manufacturer's commercial literature. Prior to test, each lift truck was serviced and adjusted according to the applicable instructions for placing new vehicles into initial service. As part of this service, the first of two maintenance evaluations was performed. After this initial servicing and prior to test, all of the internal-combustion-powered trucks were emission tested by the MERADCOM Product Assurance and Testing Directorate. These lift trucks were then retested at 100-engine-h intervals during the remainder of the test program with the final test occurring at 280 h. A summary of the emission test procedures is presented here, and a comprehensive description of the test and test results is presented in Appendix D.

Each truck was tested for emissions in three different modes. In each of the test modes, exhaust gas emissions of CO, CO^2, NO, O^2, and HC were measured at 5-min intervals during a 30-min test. In test modes 1 and 3, the test began at start (time zero) of cold engine which was then allowed to idle (600 r/min) for the duration of the test. For mode 1, the emission sensing probe was placed at a location in the test chamber to obtain a representative sample. A circulating fan was used in the test chamber during the test to uniformly mix the atmosphere. For mode 2, the throttle of the engine was propped open to the maximum governed speed after an initial warm-up period, and the sensing probe was located as in mode 1. For mode 3, the sensing probe was inserted in the exhaust pipe of the engine. The test chamber exhaust fan was on during this mode to provide open-air conditions. The exhaust fan was used to thoroughly exhaust the air in the test chamber between tests and after the warm-up period for test mode 2.

III. RESULTS

7. **Results of Productivity Comparison of Power Source Alternatives (Course A).** Three productivity measures of effectiveness (MOE) were calculated for each truck from their respective data records from Course A (200 h). The first and probably the most accurate MOE for productivity is the mean of the cycle time (X) or average cycle time in seconds to complete a cycle on Course A. Table 3 compares these statistics calculated for each truck. Comparing Xs shows that the internal-combustion-engine-powered trucks (Nos. 91, 92, 94, 95, and 106) have shorter cycle time Xs, which as an MOE for productivity, suggests that these trucks are 7.0 to 21.0 percent more productive than their electric-motor-driven counterpart (No. 103). It can also be seen that the LPG-powered forklifts, in both instances, are more productive than their gasoline-driven counterparts by 3 to 6 percent. The commercial trucks (Nos. 91 and 92) are more productive than their respective military counterparts (Nos. 95 and 94) by 1.0 and 5.0 percent. This comparative difference of the MOE is explained by the larger engine (i.e., 162 c.i.d.) in the commercial trucks versus the military trucks (i.e., 135 c.i.d.). The diesel-engine-powered truck (No.

Table 3. Productivity (Course A)

Truck No.	Average Cycle Time (s)	Average (c/Clock h)	Average (c/Engine h)
91	197 (2)	16.46 (2)	16.39 (3)
92	211 (4)	16.06 (3)	14.99 (5)
94	214 (5)	15.55 (5)	16.71 (2)
95	207 (3)	15.90 (4)	15.57 (4)
103	232 (6)	13.48 (6)	14.53 (6)
106	183 (1)	18.56 (1)	19.05 (1)

NOTE: Numbers ( ) indicate ranking of trucks from the most productive (lowest cycle time, most c/clock h or most c/engine h) to the least productive. These values are for Course A of this Power Source Test (MIL-STD-268C Course).

106) was more productive than any of the other trucks and over 7 percent better than the next best truck (No. 91). The productivity difference between the electric- and gasoline- or diesel-engine trucks was expected. However, the increase by converting identical trucks to LPG was not expected. One factor for this increase could be more efficient combustion of the gaseous fuel. The performance of the diesel (No. 106) truck is due in part to the control system which allowed changing from forward to reverse motion using only a foot pedal.

The second productivity MOE examined was the average number of cycles per hour or the rate at which a truck could operate (Table 3). This was computed by dividing cycles completed by the elapsed clockhours. One could argue the rationale of discussing these statistics. However, they take into account the pace of the test which called for periodic switching of drivers and engine shut-down and restart (for all but the electric-motor-driven truck which paused) after each cycle. This pace of test is therefore judged to correlate to an actual warehouse application of forklifts where routinely there are waits/pauses/operator breaks between cycles. Using this productivity MOE, the internal-combustion-powered trucks ranged from 15 to 38 percent (diesel) more productive than the electric counterpart. The LPG trucks were about 2 percent more productive than their gasoline counterparts.

The third productivity MOE examined was the average number of cycles per engine hour. This does not allow for any time elapsed while the engine is not running. This MOE provided a range of productivity increase of from about 3 to about 30 percent (diesel) for the internal combustion trucks over the electric truck. This MOE shows the commercial (162 c.i.d.) LPG truck to be about 9 percent more productive than the gasoline counterpart. However, the military (135 c.i.d.) gasoline-powered truck appears to be about 7 percent more productive than the LPG counterpart.

This analysis of results did not attempt to resolve the impact of productivity of the various power sources when the variable related to the driver is removed. To address this issue, the cycle data for each different test driver on each truck was examined. These statistics are shown in Table 4 and as can be seen, five of nine test drivers drove five of the trucks and three drivers drove all six trucks on Course A. Except for drivers D and S, significant loss in productivity occurs for each driver when his productivity on an internal-combustion-engine-powered forklift is compared to that using the electric-powered forklift. The productivity loss ranges from about 20 percent to nearly 30 percent. It is also significant to note that driver D turned in cycle times (high) which are independent of the power source being driven. Driver S's cycle times reflect his learning curve operating MHE as his cycle times on trucks No. 94 and No. 103 reflect his first days of employment. However, experienced drivers should operate at or near the forklift truck's capability.

Table 4. Productivity Comparison of Selected Drivers on Test Course A
(Average Cycle Time)

Driver	Truck No. 106	91	92	94	95	103	Productivity Increase Min to Max (%) (Same Driver)
D	—	242.7	238.6	236.6	234.6	235.8	2.9
G	191.4	201.0	205.6	212.3	209.5	229.2	19.7
J	—	181.9	210.0	206.3	197.4	217.5	19.6
L	178.8	192.7	207.0	211.6	204.8	231.4	29.4
S	191.9	204.1	206.2	276.1	211.7	253.9	43.9
	Productivity Increase — Min to max (%) (Same Truck)						
	7.3	33.4	16.1	33.8	18.8	16.7	

8. **Results of Productivity Comparison of Power Source Alternatives (Test Courses C (Concrete) and G (Gravel)).** The productivity MOE cycles/engine hour was calculated using the compiled results from Appendix E. These MOEs are shown in Table 5. Again, the internal combustion-powered trucks are more productive than their electric counterpart but not by the wide margins seen on Course A. This observation is attributed to the absence of high lifting stations on Courses C and G. These courses are best characterized as truck loading/unloading sequence with a maximum lift of 56 in. Therefore, in this scenario (Course C and G) the electric is more competitive than on Course A with its ramping and high lift requirements.

All trucks exhibited a drastic reduction in productivity (ranging from 12 percent to 39 percent) when operating on Course G. This is attributed to human factors in that these were trucks with no suspension equipped with solid rubber tires intended for use on hard and relatively smooth surfaces. Any surface irregularity is transmitted to the driver and his only recourse is to slow down his vehicle's pace, which is observed.

9. **Energy Consumption of Various Power Source Alternatives (Test Courses A (MIL-STD-268C), C (Concrete), and G (Gravel)).** Energy consumption results for each of the test trucks operating on each course were extracted from Appendix E and are presented in Table 6. Shown are cycles/units of energy and units of energy engine-hours. The expression unit of energy is required as gasoline and diesel fuel was measured in liters, LPG in pounds and electricity in kilowatt hours kWh. The trucks were compared based on an energy cost basis taken at one instant in time. Obviously, significant changes in their relation to each other could change the results of this analysis. Table 6, using the energy costs shown, indicates that the most productive truck (No. 106) also approached the energy economy apparent in the electric truck (No. 103). Note that the remaining trucks were more productive than the electric truck (No. 103) but were also significantly more expensive to operate from an energy cost perspective. Obviously, the diesel powered truck represented the best match of productivity (cycles/engine h) to energy cost ($/engine h). If one arbitrarily assigns each truck a mission of 1000 cycles on the MIL-STD-268C test course (Course A), the various test trucks would complete them in the time and at the energy cost shown in Table 7. Restated, these diesel trucks, for an 8 percent increase in fuel cost, can accomplish the work of four electric trucks. For a 70 percent to 100 percent energy cost increase, 7.6 to 9.3 of the forklifts like Nos. 91, 92, 94, and 95 can accomplish the work of 10 electric trucks. Although not as dramatic as the diesel/electric comparison, significant life cycle cost implications are evident even for the gas/LPG to electric comparison. If one assumes that the cost of owning (i.e., labor + amortized acquisition cost + maintenance + repair parts + salvage value) less fuel cost, of any of the trucks is about the same, we see in Table 8 that the positive productivity cost impact of even marginal increases in productivity offsets any increase in fuel costs as the cost/h of owning the truck increases.

Table 5. Productivity Comparison of Power Source Alternatives (Test Courses C (Concrete) and G (Gravel))

Truck No.	Cycles/Engine/h Course G	Cycles/Engine/h Course C	Productivity Increase (%) $\frac{C-G}{G}$
91	16.85	20.35	21
92	16.54	19.43	17
94	16.04	19.86	24
95	15.75	21.97	39
103	15.19	18.71	23
106	18.58	20.84	12

Table 6. Energy Consumption of Power Source Alternatives on Test Courses A, C, and G

Truck No.	Course	Cycle/Units of Fuel	Units of Fuel/ Engine/h	Productivity c/ Engine/h (X)	Fuel Energy Cost ($/c)	Fuel Energy Cost ($/Engine/h)
91	A	2.35 (lb)	6.96 (lb)	16.39 (3)	.078 (3)	1.288
	C	2.91	7.00	20.35 (3)	.064 (3)	1.295
	G	2.56	6.58	16.85 (2)	.072 (5)	1.217
92	A	3.11 (l)	4.82 (l)	14.99 (5)	.093 (5)	1.398
	C	4.20	4.63	19.43 (5)	.069 (4)	1.348
	G	4.42	3.74	16.54 (3)	.066 (4)	1.085
94	A	2.98 (l)	5.60 (l)	16.71 (2)	.097 (6)	1.624
	C	3.64	5.46	19.86 (4)	.080 (6)	1.583
	G	4.83	3.32	16.04 (4)	.060 (3)	0.983
95	A	2.01 (lb)	7.74 (lb)	15.57 (4)	.092 (4)	1.432
	C	2.45	8.91	21.97 (1)	.076 (5)	1.648
	G	2.14	7.37	15.75 (5)	.086 (6)	1.363
103	A	1.51 (kWh)	9.60 (kWh)	14.53 (6)	.046 (1)	0.672
	C	1.42	11.79	18.71 (6)	.049 (2)	0.825
	G	1.56	9.74	15.19 (6)	.045 (2)	0.682
106	A	5.56 (l)	3.40 (l)	19.05 (1)	.050 (2)	0.952
	C	6.69	3.12	20.84 (2)	.042 (1)	0.872
	G	9.03	2.06	18.58 (1)	.031 (1)	0.860

NOTE: Gasoline Cost = 0.29/l.
Diesel Cost = 0.28/l.
LPG Cost = 0.185/lb.
Electric Cost = .07/kWh.

Table 7. Time and Energy Cost to Complete 1000 Cycles on MIL-STD-268C Test Course for Six Different Lift Trucks

Test Truck No.	Energy Type (Fuel)	Engine/h Required to Complete 1000 Cycles	Energy Cost ($) to Complete 1000 Cycles
91	LPG (Commercial)	61.00	78.57
92	Gas (Commercial)	66.70	93.24
94	Gas (Military)	59.84	97.19
95	LPG (Converted Military)	64.22	91.95
103	Electric	68.84	46.26
106	Diesel	52.49	49.98

NOTE: See Table 6 for fuel costs.

Table 8. Total Cost of Performing 1000 Cycles for Various Ownership Costs from $10 to $25/Engine/h

Truck No.	Engine/h Required	Cost of 1000 Cycles at Fixed Costs of:				Energy Cost for 1000 Cycles	Total Cost for 1000 Cycles at Fixed Costs of:			
		$10/h	$15/h	$20/h	$25/h		$10/h	$15/h	$20/h	$25/h
91	61.00	610	915	1220	1525	78.57	688.57	993.57	1298.57	1603.57
92	66.70	667	1000	1334	1668	93.24	760.24	1093.24	1427.24	1761.24
94	59.84	598	898	1197	1496	97.19	695.19	995.19	1294.19	1593.19
95	64.22	642	963	1284	1605	91.95	733.95	1054.95	1375.95	1696.95
103	68.84	688	1032	1378	1721	46.26	734.26	1078.26	1424.26	1767.26
106	52.49	525	787	1050	1312	49.98	574.98	836.98	1099.98	1361.98

NOTE: See Table 6 for fuel costs.

10. Impact of Operating on Hardstand Versus Unimproved Surfaces. From Table 6 we see significant reductions in productivity occurred when the trucks operated on the Gravel Course (G) instead of the Concrete Course (C). Corresponding with this reduced productivity is the reduced fuel consumption. Again the best productivity versus energy cost match on Courses C and G is the diesel-powered lift truck. Energy costs were in the same formation as seen on Course A. The lower energy cost on G is attributed to the productivity of the truck being ridden limited by the dynamics created by the unimproved surface. In other words, the driver slowed the truck down for creature comfort thereby reducing both productivity and fuel cost. This analysis supports the application rule of thumb that solid-rubber-tired trucks should be used on hard, smooth surfaces only. When this rule was violated purposely in test (Course G versus C) productivity drops from 14.9 to 28.3 percent were observed.

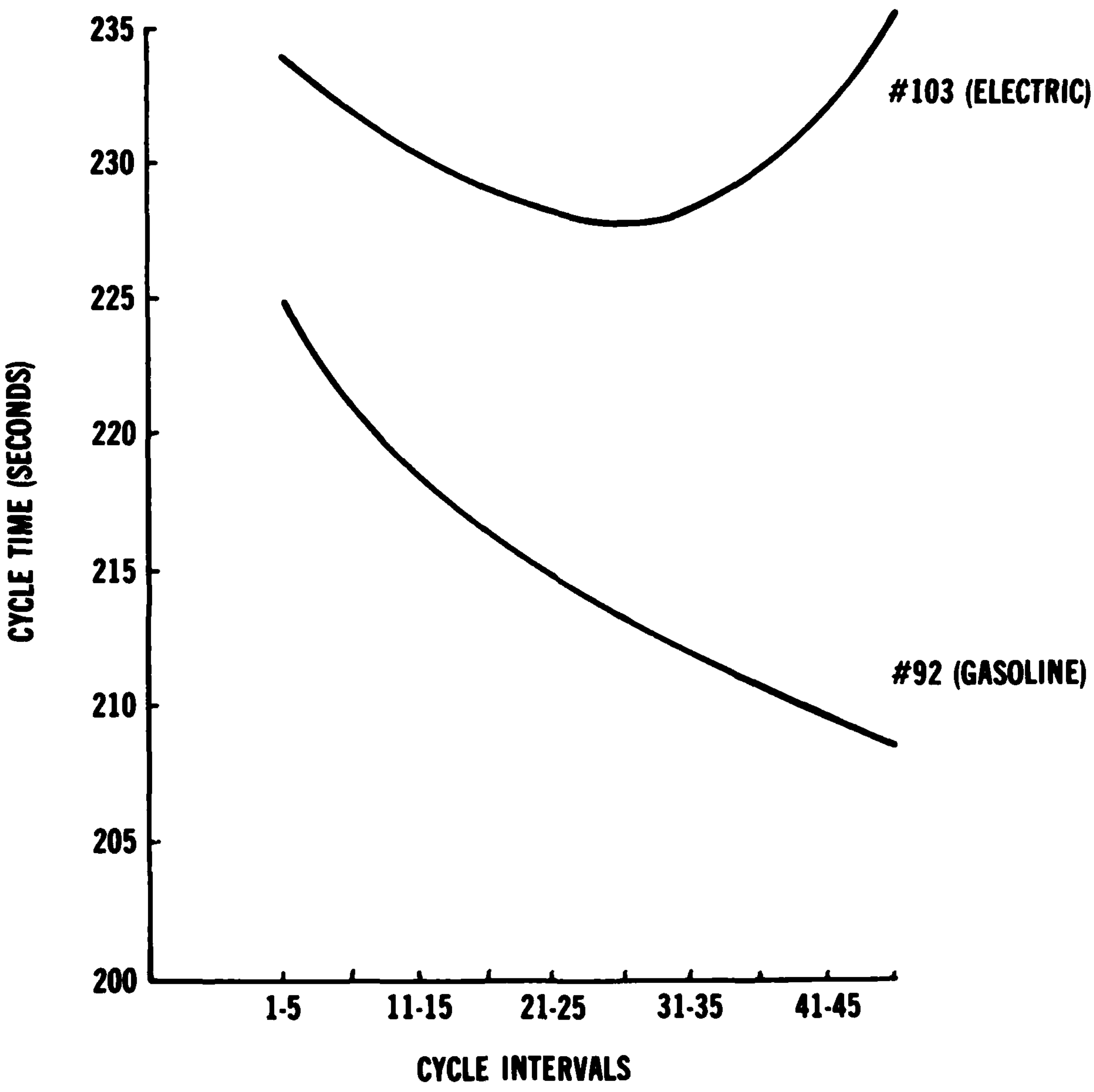
11. Impact of Battery Charge Life on Productivity of an Electric-Motor-Driven Truck (Test Course A). Initially the test plan for the electric lift truck (No. 103) specified that a battery would be used until the highlift of the MIL-STD-268C test course could not be completed without pausing. Thus, the length of time a battery would be used, or battery life, would commence with a fully charged battery and would end when the battery was discharged to the point that a highlift could not be completed. However, following the specified procedure, several motor failures attributed to overheating occurred early in the test. Therefore, for the remainder (and majority) of the test, the lift truck batteries were routinely exchanged for charged ones after 50 c. After this ammendment to the test plan, the electric lift truck completed the test with only one additional electric motor failure.

The question of an electric lift truck's productivity across this duty day of 50 c was examined using cycle times from each of the 50 c within its duty day. Mean cycle times and their standard deviations were calculated by grouping all cycle times in intervals of 5 c as they occurred from 1 c to 50 c. These are shown in Table 9 together with those for the most productive gasoline lift truck No. 92. The 50 cycles used for No. 92 were the first 50 c after fuel was added. Observe that the maximum range of the electric truck is only 8.7 s while for gasoline baseline it was 17.9 s. These data await a full statistical analysis. However, the results indicate that the greatest variability of productivity across the 50-c duty day is exhibited by the gasoline-powered truck No. 92. Truck No. 92 is most productive during its last 5-c interval, while No. 103 is least productive during this 5-c interval and, as noted previously, further use without changing the batteries leads to overheated drive motors. Figure 13 was prepared by manually plotting and smoothing the data from Table 9. It illustrates that the gap between the productivity of No. 92 and No. 103 widens as the duty day progresses. Figure 14 presents typical discharge and recharge curves for a lead-acid battery of the type used during this test. Note that the voltage drop is precipitous after about 4 h of use and that the general shape of No. 103's productivity curve shown in Figure 13 correlates inversely to the voltage curve shown in Figure 14. The average discharged battery specific gravity was 1.143 during the test. Comparing this to

Table 9. Mean Cycle Times and Standard Deviations

Cycle Group	No. Points	Cycle Time (s) Mean (X)	Cycle Time (s) Deviation (σ)
		Truck B (No. 92)	
1–5	210	225.2	52.1
6–10	210	217.1	38.2
11–15	200	218.7	43.9
16–20	195	215.7	40.1
21–25	195	209.0	33.7
26–30	190	213.5	33.0
31–35	178	215.6	42.4
36–40	175	214.2	41.4
41–45	173	210.0	31.9
46–50	164	207.3	29.4
		Truck E (No. 103)	
1–5	300	232.5	32.6
6–10	300	233.8	45.2
11–15	300	234.5	28.7
16–20	300	232.0	22.4
21–25	289	226.8	24.6
26–30	285	228.8	26.1
31–35	271	229.6	23.1
36–40	258	228.8	21.5
41–45	225	232.1	28.4
46–50	195	235.5	28.2

PRODUCTIVITY (AVERAGE CYCLE TIME) COMPARISON OVER THE FIRST FIFTY (50) CYCLES OF THE WORK PERIOD*



*STARTING WITH FULL FUEL TANK (#92) AND FULLY CHARGED BATTERY (#103)

Figure 13. Productivity curve of no. 103.

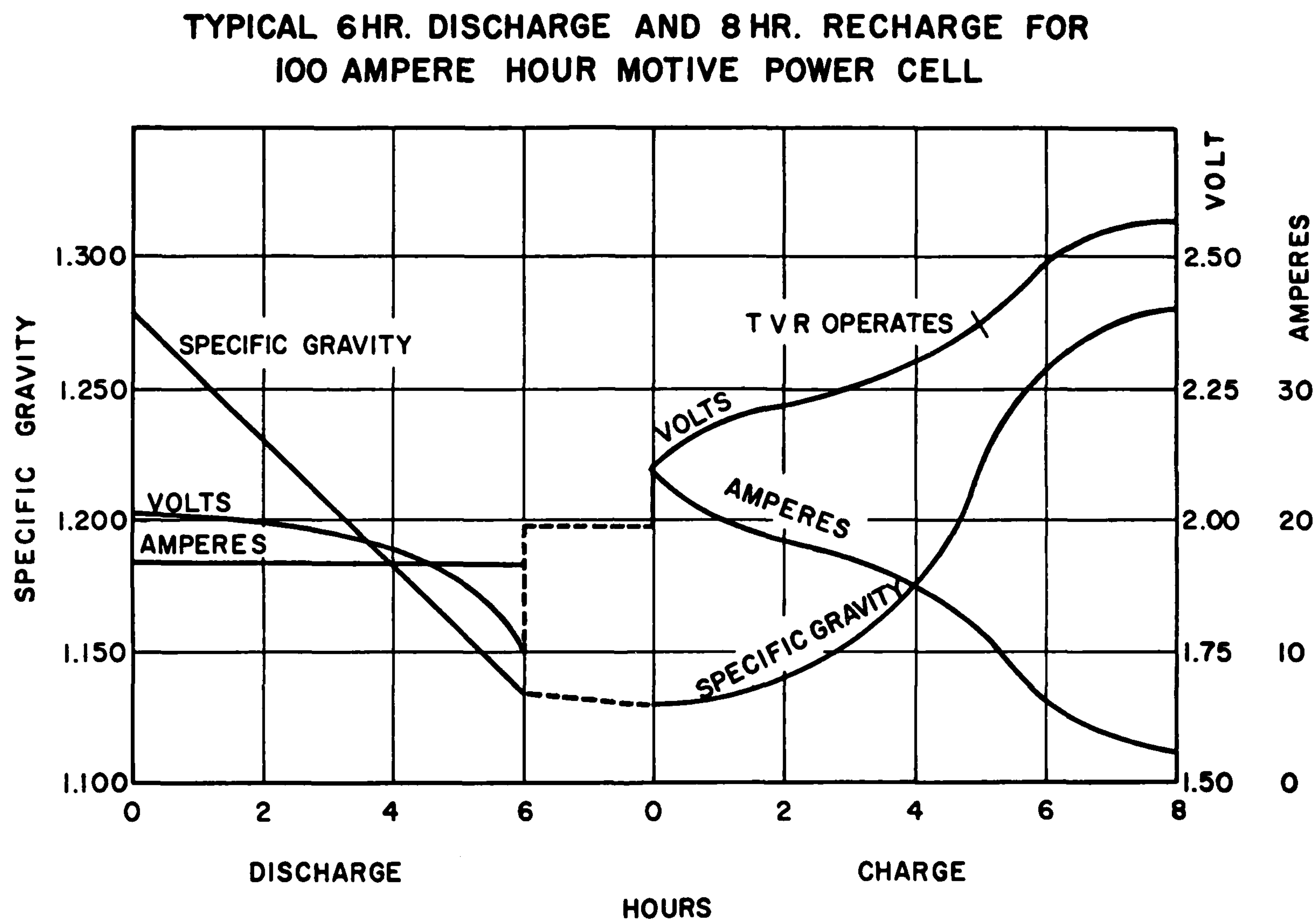


Figure 14. Typical discharge and recharge curves for a lead-acid battery of the type used during this test.

Table 9 supports the conclusion that 50 c on the MIL-STD-268C test course represents a realistic estimate of the work potential of the 36-V, 850-Ah, lead-acid industrial truck battery. The electric truck, although slower than its internal combustion-engine-powered counterparts, will exhibit less variability of productivity (cycle times) during a 50-c duty day. However, the decline in productivity beyond these 50 c will be precipitous and would also result in damage to the lift truck electric components.

12. **Observed Sound Level Results of Various Power Sources.** Sound level results for each test truck are shown in Table 10 and indicate that the electric truck, as expected, emits significantly less noise than the other power sources. The maximum sound levels for the remaining trucks ranged from 91 dBA to 93 dBA and except for the diesel, which was significantly noisier, were about the same (65.0 dBA to 67.5 dBA) at idle. All of the trucks except for No. 103, exceeded the steady-state maximum sound level of 85 dBA permitted by the Army Surgeon General.[3]

13. **Reliability, Availability, and Maintainability Characteristics of Alternate Power Sources for MHE.** Failure incidents which occurred during test were annoted and fully described on Equipment Performance Reports. These are summarized in Appendix F. The failure incidents were then scored using the Failure Scoring Tree shown in Figure 15. Note that this Failure Scoring Tree isolates those failure incidents judged to be independent of the power source. As an example, crossover tube failures were repeatedly noted. However, these occurred on all the trucks from this manufacturer and therefore they were not scored as a failure attributable to the power source type. The manufacturer was responsive to the noted problem and provided modified crossover tubes which when installed significantly reduced the failure rate.

The failures scored using the Failure Scoring Tree are shown in Table 11 for each truck. Estimates of reliability, availability, and maintainability derived from these data are summarized in Table 12. These estimates are based on the following assumptions:

a. Statistical test indicates that the exponential distribution of time to failure could be assumed.

b. The mean-time-to-repair values shown are the means of the assumed lognormal distribution.

c. To obtain a maintenance ratio (maintenance manhours/operating h) 1.5 h of scheduled power source maintenance/500 operating h was used.

A nonparametric statistical test on the mean-time-between failure on each power source type was performed and indicated that the diesel ranked first (lowest MTBF) and no significant difference could be determined among the gasoline, LPG, and electric trucks.

[3] Mil-Std 1474.

Table 10. Noise

Truck No.	Idle — dBA	Lifting Rated Load at Max Governed Speed
91	67.0	93.0
92	66.5	92.0
94	67.5	93.0
95	65.0	91.0
103	62.0*	78.0
106	72.0	93.0

* Truck No. 103 (Electric) — Switch on, Truck Static.

NOTE: Test equipment used for noise measurement was a General Radio 1565-B Sound Level meter reading in decibels (dB) on the A scale (dBA). All readings were taken six in. from the operator's ear.

Failure Scoring Tree for Power Source Evaluation

Steps	Guidelines		Classification
1	Does the incident concern RAM? Yes	No	Non-RAM oriented
2	Was incident detected during initial inspection? No	Yes	No-test
3	Did incident result from test abuse, unrealistic operating conditions, accident, or improper maintenance or operating procedures? No	Yes	No-test
4	Was the incident independent of the forklifts power source (automotive subsystem)? No	Yes	No-test
5	Was incident detected during an inspection or operation for which no action or only authorized scheduled maintenance was required? No	Yes	No-test
6	Was incident a scheduled replacement/service? No	Yes	Scheduled maintenance
7	Was incident due to improper maintenance or operating instructions? No	Yes	Unscheduled maintenance
8	Was incident caused by another incident? No	Yes	Unscheduled maintenance
9	Was the incident caused by an incipient malfunction detected during scheduled maintenance or detected during operations for which correction can be deferred to a scheduled maintenance and corrected at that level? No	Yes	Unscheduled maintenance
10	Was (or could have) the incident corrected within 30 min? No	Yes	Unscheduled maintenance
11	Is incident an actual malfunction for which maintenance can be deferred for correction to the next scheduled maintenance? No	Yes	Unscheduled maintenance
	Classify as unscheduled maintenance and system failure.		

NOTE: The first answer to a question chosen from the column to the right of the question determines the classification for the incident.

Figure 15. Failure scoring tree.

Table 11. Exhibited Power Pack Failure Modes for System Failures.

Type	Failure Mode
Diesel	None
Electric	(1) 400 A fuse blew in main power circuit. (2) 400 A fuse blew in contactors. (3) Motor coil AY field windings burned out. (4) Hydraulic pump motor overheated.
Gasoline	(1) Spark plug failed. (2) Spark plug misfired. (3) Loose hose caused loss of vacuum. (4) Fuel leaked from carburetor and intake manifold (fuel in crankcase).
LPG	(1) Fuel filter clogged twice. (2) Fuel lock filter was bad. (3) Fuel lock failed.

Table 12. Power Source Reliability and Maintainability Test Summary (280 Test Hours Per Truck)

Power Source Type	No. of Test Trucks	No. of Failures	Mean Time Between Failures	90% Lower Confidence Limit*	Mean Time To Repair**	Maintenance Ratio***
Diesel	1	0	—	122	—	0.0030
Electric	1	4	70	35	1.86	0.0816
Gasoline	2	4	140	70	0.95	0.0211
LPG	2	4	140	70	0.95	0.0131

* Value of Mean-Time-Between-Failures for which there is 90% confidence that further testing would not predict a lower value.

** Lognormal mean.

*** *Maintenance manhours/operating h (1.5 h/500 operating h — scheduled maintenance estimate). All unscheduled maintenance manhours (even manhours for incidents not* counted as failures) were used to calculate maintenance ratio.

Although not directly related to the initial objective of this test, drive wheel tire lift was observed to be very short. The short life was independent of truck power source type, truck manufacturer, and tire manufacturer. The short life was attributed to the pace of the test (i.e., nonstop) handling maximum rated loads, to high ambient temperatures during summer months, to test course surface conditions imposed by gravel course and by the chatter portion of the MIL-STD-268C test course. Note that the concrete courses were routinely (weekly) cleaned with an industrial floor sweeper/vacuum.

Figures 16 and 17 are examples of the tire-rim separation and tire failure which occurred repeatedly during the test. As few as 90 h was required to produce the separation characterized by these figures. Based on the results of this test, a very significant cost of forklift ownership, independent of power source type, is replacement of drive tires.

A problem that affected the availability of the LPG-engine-powered trucks was the difficulty of starting the engines in cold weather. This is an inherent problem of this fuel which is stored in the fuel tank as a liquid but converted to a gas in the regulator before entering the carburetor (Figure C16). With the reduction in pressure of the fuel in the regulator, the fuel absorbs energy which tends to freeze the regulator and prevent the engine from starting. The regulator is water heated, by the engine water cooling system, but for the first start-up of the day, there is no heat available until the engine is running. Storing LPG trucks in a heated building in cold weather or using an electric-engine pre-heater should eliminate this starting problem.

14. **Results of Exhaust Emission Comparison of Power Source Alternatives.** Results of exhaust emission tests are presented in Appendix D. Table D1 summarizes the results of the tests and illustrates the favorable aspects of the LPG and diesel-powered trucks over the gasoline-powered trucks. The standard diesel-engine-powered truck, however, emits a characteristic odor that is more offensive than the LPG trucks. A new development in diesel engines designated as "clean burning" diesel engines has been identified which may have the potential for low exhaust emissions and reduced odor. A future MERADCOM report will investigate this new development in diesel engines.

Figure 16. Tire-rim separation.

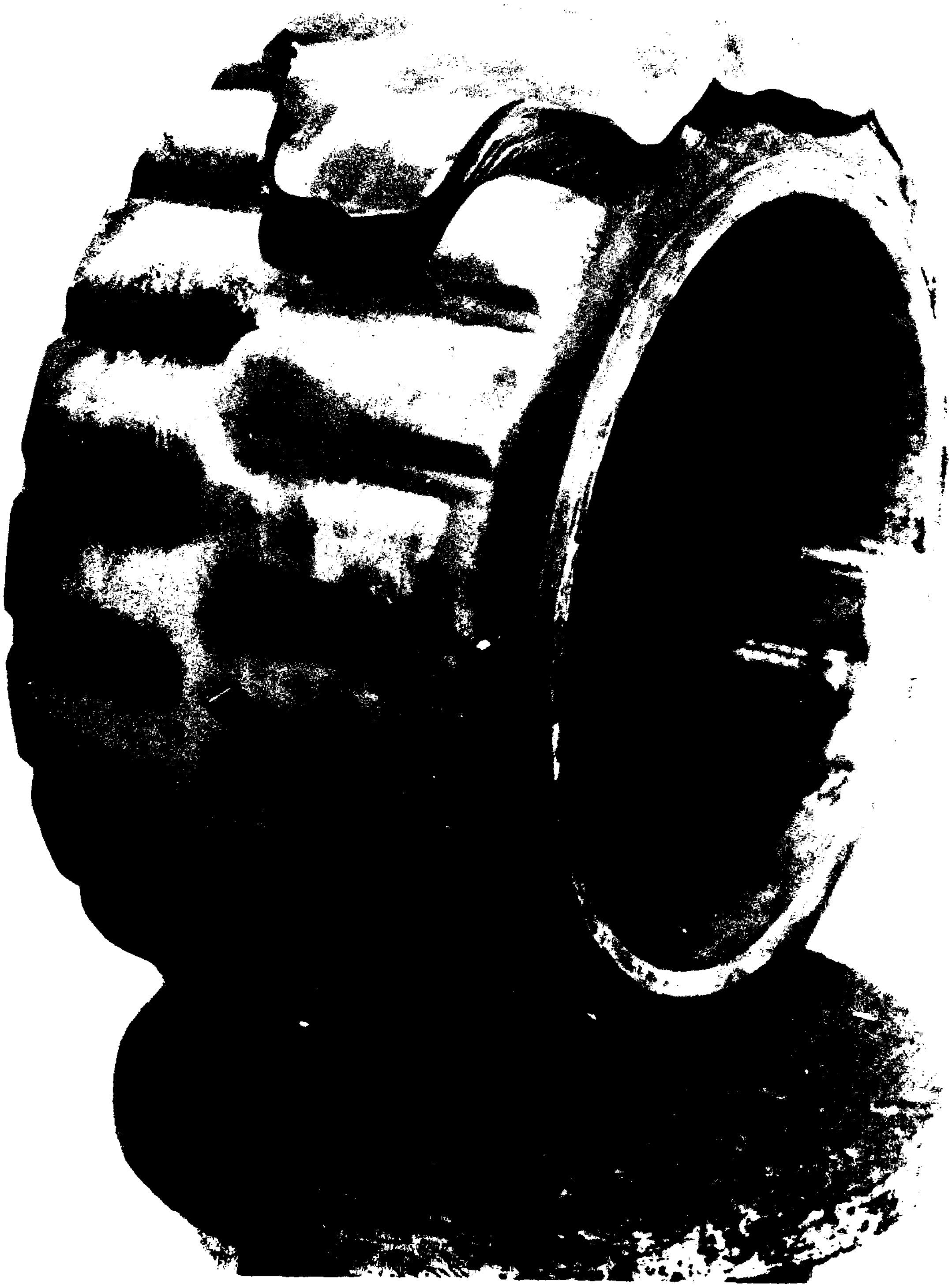


Figure 17. Tire failure.

IV. CONCLUSIONS

Internal-combustion-engine-powered lift trucks are inherently more productive than their battery-powered electric-motor-driven counterparts. This inherent productive capacity is realized only with trained/experienced drivers motivated to operate the lift truck at or near its potential.

Diesel-powered lift trucks (the most productive truck in this test) can operate at energy economics approaching that of battery-powered, electric-motor-driven lift trucks (the most economical considering energy costs).

The cost advantage of productivity gained by using the other internal-combustion-engine-powered lift trucks in lieu of the electric lift truck generally affects increased energy consumption (and cost).

Noise levels of all lift trucks at the operator's station tested, except for the electric-motor-driven (78.0 dBA), exceeded the 85 dBA steady-state allowed by MIL-STD-1474B.

Except for the battery-powered, electric-motor-driven lift truck, the diesel-powered lift truck demonstrated exhaust emissions characteristics (CO) potentially more compatible for safe indoor use than either the gasoline- or LPG-powered lift trucks.

Cold weather starting problems associated with the LPG-powered lift trucks affect the increase in productivity and reduced energy costs which are realized by using LPG lift trucks in lieu of gasoline-powered lift trucks.

The utility of electric-motor-driven lift trucks is degraded by short battery charge life which in the MIL-STD-268C test course was 4 h to 5 h. (An around-the-clock operation would require at least 2 spare batteries and 2 charges per truck).

These conclusions relative to lift truck power source alternatives are summarized in Table 13. As an example, Table 13 indicates that the diesel-engine-powered lift truck has energy costs similar to electric-motor-driven lift trucks; possesses the best inherent productivity characteristics; does not satisfy MIL-STD-1474B for noise emission; exhibits high RAM characteristics; has exhaust emission characteristics more compatible with indoor use than the LPG- and gasoline-powered lift trucks; and has the most utility of all power sources evaluated.

The magnitude of the differences by power source type for each parameter shown in Table 13 is fully developed in the body of the report.

The cause of the tire-rim separation which occurred repeatedly throughout the test has not been determined.

Table 13. Summary Conclusions for Power Source Evaluation

Type Power Source	Energy Cost	Productivity	Noise (MIL-STD-14743)	Reliability, Availability Maintainability	Emissions Safety	Utility (Flexibility of Use)
Diesel	1	1	Over 85 dBA	High	2	1
Gasoline	3	3	Over 85 dBA	High	4	2
LPG	2	2	Over 85 dBA	High	3	3
Electric	1	4	Under 85 dBA	High	1	4

NOTE: Ranking from 1 (most desirable) to 4 (least desirable).

V. IMPLEMENTATION

MERADCOM'S plan of action to critically review and revalidate the regulations involving safe use of MHE is as follows:

- Develop safety criteria for use of MHE in Class V (ammunition) handling operations.

- Develop definitive test to assess pass/fail of MHE versus the criteria identified above.

- Provide test vehicle (forklift equipped with "clean burning" diesel).

- Prepare coordinated plan of test.

- Develop draft requirement document.

- Obtain available data on "clean burning" diesel forklifts.

- MERADCOM will use results of the above review and this test to update MIL STD MIL-T-52932. This update will include provisions to procure diesel-engine-powered lift trucks with the safety, emission and energy efficiency characteristics demonstrated in this evaluation.

- MERADCOM will investigate the cause of tire-rim separation as part of the FY83 MACI Program under Project No. A3T53614631.

APPENDIX A

DESCRIPTION/SPECIFICATIONS

1. The work to be undertaken shall consist of manufacture and delivery of three forklift trucks as follows:

   a. Truck, Forklift, Gasoline-Engine-Driven.

   b. Truck, Forklift, Liquid-Petroleum, Gas-Powered.

   c. Truck, Forklift, Electric-Motor-Driven, 36-v, Type EE.

2. The forklift trucks shall have the following characteristics:

   a. **Load Capacity**: 4000-lb at 24-in. load center.

   b. **Lift Height**: The unladen forklift trucks shall have a lift height of 180 in. when measured from the ground to the top surface of the forks, with the upright in true vertical position.

   c. **Lowered Height**: The unladed forklift trucks shall have a lowered mast height not to exceed 83 in. when measured from the ground to the highest point of the upright assembly, with the upright in the true vertical position.

   d. **Free Lift**: The unladen forklift trucks shall be capable of raising the forks a minimum of 45 in. without any increase in lowered height when measured from the ground to the top surface of the forks with mast in true vertical position.

   e. **Forks Length**: Forks shall not be less than 38 in. long nor more than 40 in. long.

   f. **Load Backrest**: Forklift trucks shall be equipped with a removable load backrest not less than 48 in. high when measured from the top surface of the forks to the highest point of the backrest.

   g. **Overhead Guard**: Forklift trucks shall be equipped with an overhead guard not to exceed 85 in. for internal combustion-engine-driven trucks, and not to exceed 83 in. for electric-motor-driven truck, when measured from the ground to the highest point of the overhead guard.

h. **Fork Carriage**: Forklift trucks shall be equipped with a fork carriage in accordance with American National Standard ANSI MM11.4-1973, *Forks and Fork Carriers for Powered Industrial Forklift Trucks.*

i. **Mast**: Forklift trucks shall be furnished with rollertype three-stage mast.

j. **Transmission**: Internal combustion-engine-driven forklift trucks shall be furnished with a continuous drive power shift transmission. Transmission shall provide for positive inching control of the truck.

k. **Battery**: Electric-motor-driven forklift truck shall be powered by a 36-v lead-acid battery with a minimum of 840 Ah at a 6-h rate. Cable end shall be equipped with EC battery connectors.

l. **Tires**: Forklift trucks shall be equipped with cushion rubber tires.

m. **Power Steering**: Forklift trucks shall be equipped with power steering.

n. **Power Brakes**: Forklift trucks shall be equipped with power brakes.

3. The forklift trucks shall be equipped with standard instruments, components, and accessories normally required for the safe and effective operation of the truck. The forklift trucks shall conform to American National Standard ANSI B56.1-1975, *Safety Standard for Powered Industrial Trucks.*

4. Manuals: The contractor shall furnish two operational, maintenance, and parts manuals for each forklift truck. Maintenance manuals shall include troubleshooting procedures, repair directions, preventative maintenance schedules, lubrication orders, and hydraulic and wiring schematics.

5. Warranty: Warranty shall be the normal standard warranty, but shall not be less than:

6 mo or 1000 h, for defects in materials and workmanship.

1 yr or 2000 h on engines, transmissions, driveline components, electric motors, and electric control panel components.

APPENDIX B

TEST GUIDELINE FOR EVALUATION OF POWER SOURCES

IN FORKLIFT TRUCKS

1. **Introduction.** This is a suggested guideline to perform evaluation testing and analysis of four different power sources utilized on forklift trucks. Six 4,000-lb capacity forklift trucks will be used for this evaluation. One truck will be a standard gasoline-engine-powered unit obtained from Army stock, one truck will be an identical standard unit converted to LPG fuel, four trucks will be commercially procured models, one of each supplied with diesel-engine-power, gasoline-engine-power, electric-motor-power, and LPG power. The evaluation will include, but will not be limited to, energy consumption, environmental impact of exhaust emission and noise output, adjustment and maintainability, safety, efficiency, economy, productivity factors, and reliability.

2. **Background and Orientation.** The basic Army forklift fleet is comprised of gasoline-engine-driven and electric-motor-driven trucks. Gasoline-powered trucks are used in general warehousing operations, while electric trucks are used in hazardous operations, such as ammunition handling, or controlled humidity warehouses. Growing concern is being expressed by Army depots relative to environmental effects of exhaust and noise pollutants and the ability of warehousing operations to meet OSHA standards. Other factors of growing concern include availability of gasoline as an energy source, overall conservation of energy, and increased operating costs. Also impacting on Army materials-handling operations is the ability to move supplies quickly and in large quantities when supporting combat operations. Through the effort undertaking by the test program described herein, data will be derived from which an initial comparison of forklift truck power sources can be made.

3. **Objectives.** To obtain comparative data of power sources used in forklift truck operation through operation over a prescribed test course and under controlled test conditions to include:

a. Productivity.

b. Exhaust emissions.

c. Noise levels.

d. Energy consumption.

e. Reliability.

f. Maintainability.

g. Operating costs.

h. Safety ramifications.

The data obtained will be used to assess the relative and absolute merits of various forklift truck power plants.

4. **Plan of Test.** The detailed plan of test is left to the discretion of the test activity. Tests will be performed over a prescribed test course, in inclosed chambers, and in specific controlled environments. Data sheets and information to be recorded will be mutually developed between Warehouse and Depot Group, Mechanical Equipment Division, Mechanical and Construction Equipment Laboratory, and the test activity. The tests to be performed and data to be collected will include:

a. **Productivity.** Utilizing a test course similar to that shown in Figure B1, operate each test vehicle for 200 h. Operation shall be as described in Paragraph 5a. Record total tons per operating day handled per test unit. Utilizing a test course similar to that shown in Figure B2 and described in Paragraph 5b, operate each test vehicle for 80 h–forty h on a concrete surface, 40 h on a gravel or nonprepared surface. Record total tons handled/operating d/vehicle. All vehicles should be operated for no less than 7 h/d or until fuel is consumed or battery in electric truck is discharged, whichever occurs first. (Discharged battery will be determined by inability to lift rated load.) Each day should commence with full fuel tank or fully charged battery.

b. **Exhaust Emissions.** When operating on the test courses prescribed above, take an exhaust analysis of ICE trucks at the outlet of the exhaust pipe once every 24 h. Analysis should be taken alternatively equivalent to engine idle and engine full rpm. For electric-motor-powered trucks, measure hydrogen in the battery compartment. ICE powered equipment exhaust analysis should include, by ppm, carbon dioxide, carbon monoxide, nitrogen dioxide, aldehydes, and benzine hydrocarbons. Place the ICE trucks in a chamber where the atmosphere can be analyzed. Measure the atmosphere to determine ppm of carbon monoxide, carbon dioxide, nitrogen oxide, nitrogen dioxide, aldehydes, and benzine hydrocarbons. Operate the truck engines for ½ h at engine idle, remeasure atmosphere. Continue operating the engine for an additional ½ h at full rpm and remeasure the atmosphere. This test should be performed prior to start of operation on the test course, after 100 h of operation on the test course and after 200 h on the test course.

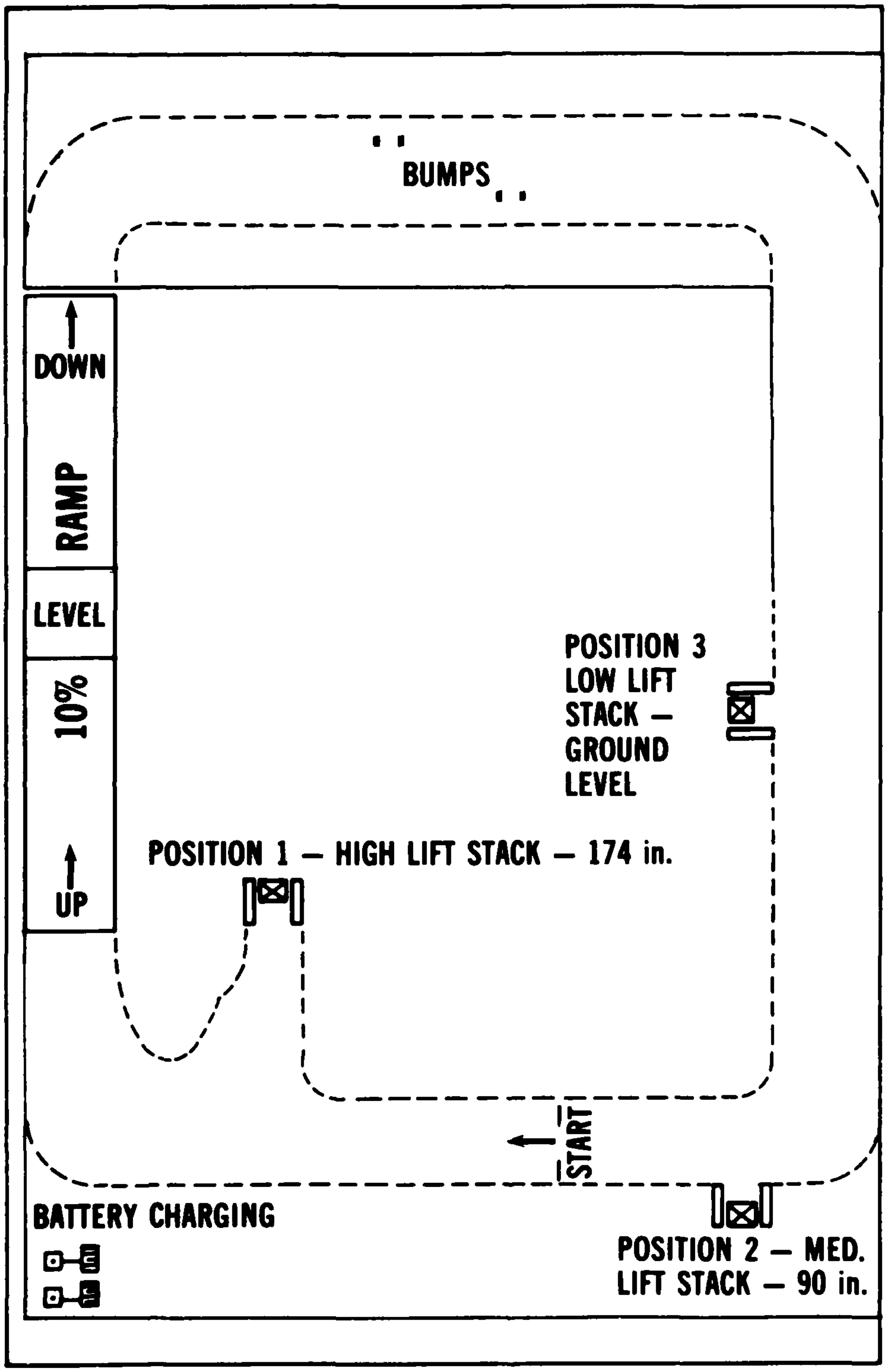


Figure B1. Materials handling equipment test course.

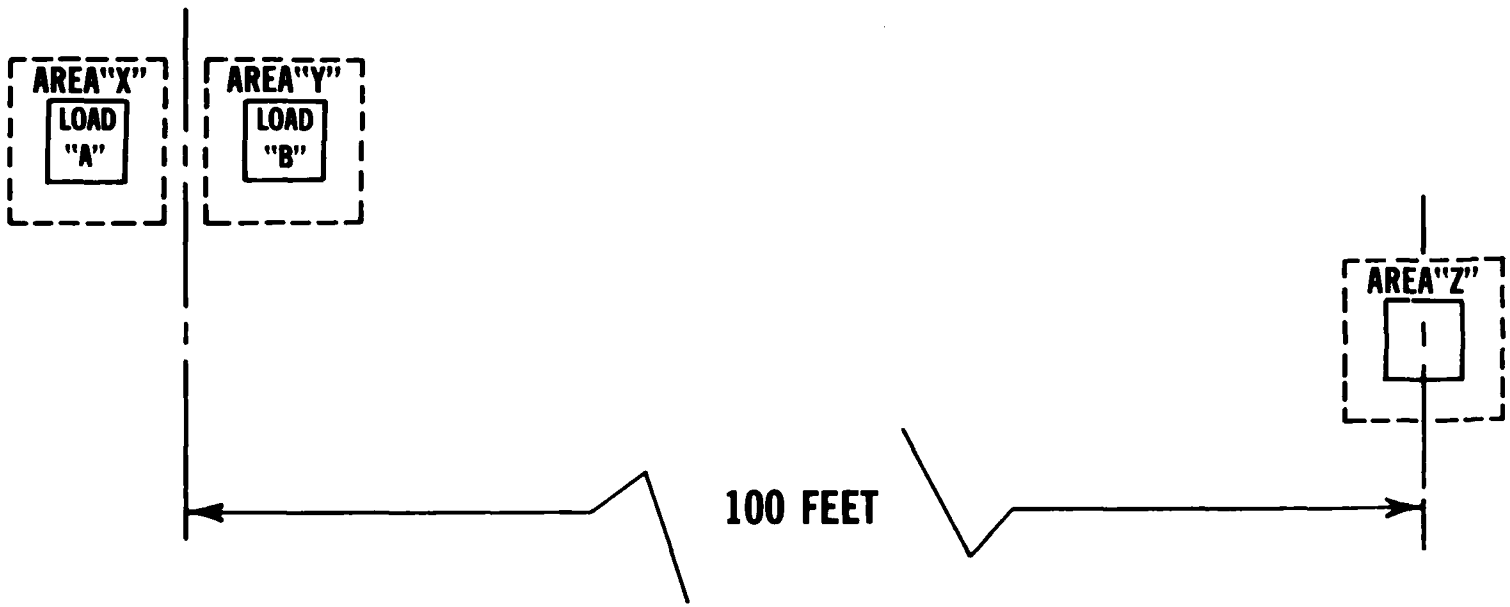


Figure B2. Test course (80-h).

c. **Noise Levels.** The noise level of the forklift truck shall be measured as follows.

(1) **Operator's Station.** Measure equivalent continuous noise levels (LEQ) in accordance with MIL-STD-1474A at the operator's station when operating on the test course. Duty cycle test shall be run in lieu of the steady-state test of MIL-STD-1474A. Minimum speed of negotiating the course shall be equivalent to traversing 20 c/h. All lifting and lowering operations shall be accomplished with the truck stationary at maximum lifting and lowering speed. Cumulative noise exposure measurement shall require a minimum of 1 h of continuous operation on the test course.

(2) **Exterior.** Measure the exterior noise level in accordance with SAE J88 except that the microphone shall be within 24.5 ft from the centerline of travel. Noise measurements should be taken within the first 50 h of operation and again at each 50-h increment for a total of 4 tests.

d. **Energy Consumption.** Record energy consumed when forklift trucks are operated over test courses (Figures B1 and B2). Consumption shall be measured as follows:

(1) Diesel-Engine Forklift Truck – liters of diesel fuel.

(2) Gasoline-Engine Forklift Truck – liters of gasoline.

(3) LPG Forklift Trucks – pounds of LPG.

(4) Electric Forklift – amount of ampere hours put back in battery to obtain full charge.

e. **Reliability.** Record all failures, breakdowns, malfunctions, or inability to perform. Describe each incident and possible cause, if known. Record total hour meter reading at time of incident and number of hours since last incident. Record condition which indicated probable failure, such as failed to start, would not lift load, excessive engine or hydraulic noise, lack of power, or any other symptom which indicated possible failure or malfunction.

f. **Maintainability.** Record manhours and clockhours to perform any maintenance. Normal preventative maintenance in accordance with the manufacturer's manual shall be recorded separately from corrective maintenance. Record manhours and clockhours to perform the following:

(1) Diesel and Gasoline-Engine-Powered Fork Trucks:

(a) Remove, replace and adjust all engine-driven belts.

(b) Remove and replace alternator.

(c) Remove and replace regulator.

(d) Remove and replace all filters, screens, and strainers in hydraulic system.

(e) Remove and replace engine coolant system hoses.

(f) Drain engine lubricating oil, remove and replace oil filter elements, and refill crankcase.

(g) Remove and replace fuel filter elements.

(h) Disconnect battery cables, remove and replace batteries, and reconnect battery cables.

(i) Drain torque converter oil and transmission oil, remove and replace all filter elements and strainers, and refill converter and transmission.

(j) Remove and replace starter.

(k) Bleed and adjust brakes and refill master cylinder.

(l) Record time to fill fuel tank in liters per minute. (Note: This should be done each time fuel is put in tank.)

(2) LPG-Powered Fork Trucks:

(a) Same as f(l)(a) thru 1.

(b) Remove and replace LPG tank. (Note: This should be recorded each time tank is changed.)

(3) Electric-Powered Fork Trucks:

(a) Remove and replace drive motor brushes.

(b) Remove and replace hoist and tilt motor brushes.

(c) Remove and replace steer motor brushes.

(d) Remove and replace all contractor tips.

(e) Remove and replace all filters, screens and strainers in hydraulic system.

(f) Bleed and adjust brakes and refill master cylinder.

(g) Remove and replace battery.

(h) Remove and replace circuit boards in controller.

(i) Remove and replace all fuses.

Note: f(1), (2), and (3) should be performed at the end of the 200-h and 80-h tests and shall be performed by three different mechanics or teams as required. All maintenance procedures shall be accomplished in accordance with the manufacturer's manual. Where procedures are not covered in the manufacturer's manual, it will be so recorded along with the procedure used. List any special tools or equipment used or required to make repairs.

g. **Operating Costs.** All costs incurred for operation and maintenance shall be recorded for each truck individually. Such costs shall include:

(1) Fuel costs.

(2) Preventative maintenance parts (oil filters, etc.)

(3) Repair parts costs.

(4) Lubricants and lubrication.

(5) Maintenance personnel costs when performing actual maintenance functions.

(6) Battery electrolyte.

(7) All other costs not directly test costs.

h. **Safety Ramifications.** Record all unsafe or suspected unsafe conditions associated with operation and maintenance of the forklift trucks, including the handling of fuels and battery electrolyte. List all safety requirements to be followed in the handling and storage of diesel fuel, gasoline, LPG, and battery-electrolyte and for fueling internal-combustion-engine-driven trucks and charging electric-powered trucks.

5. **Administrative Information**: The forklift trucks to be utilized in this test program, as indicated in paragraph 1, will be furnished by the Mechanical and Construction Equipment Laboratory, Mechanical Equipment Division. Instrumentation and recording devices should be provided by the test activity. Data collection forms or records shall be jointly prepared by Mechanical Equipment Division personnel and test activity personnel. Milestone plan and identification shall be jointly prepared between Mechanical Equipment Division personnel and test activity personnel. Personnel required from the test activity should include 1 test monitor or director, 4 forklift truck operators, 2 maintenance personnel (1 of which should have a background in internal combustion engine maintenance, and 1 with a background in electric-motor-power maintenance), and 2 data collectors. (Operators should alternate as data collectors.) Facilities and instrumentation will be jointly identified by Mechanical Equipment Division and test activity personnel.

a. **Operational Procedure for 200-h Test Course (Figure B1).** The truck under test shall begin watch cycle at the point labeled start on test track identified in the Test Plan. The truck shall execute a 90-degree turn into the high stack position and retrieve the 4000-lb load. Upon retrieval of the load, the forks shall be lowered to the carry position (approximately 6 in. above the ground), back away from the high lift position executing a 90-degree turn such as to proceed in a forward direction toward the ramp. The truck shall proceed to a point approximately ½ of the way up the forward slope of the ramp and come to a complete stop for 5 s to 7 s holding the truck with the service brakes. Operation will then proceed over the ramp and around the test track to position marked low-lift stack, traversing across the obstacles indicated on test track diagram. A 90-degree turn shall be backed away from the low-lift stack area and a 90-degree turn executed such as to continue in a forward direction to the medium lift stack area, where a second 4000-lb palletized load has been prepositioned. A 90-degree turn will be executed into the medium stack area and the load retrieved. After retrieval the load shall be lowered to carry position, the truck backed out of the area and a 90-degree turn be executed such as to position the truck to proceed in a forward direction to the high lift stack area. A 90-degree turn shall be executed into the high-stack area and the load deposited at the high-lift position, operation shall proceed as previously described from the high-lift area to the low-lift area where the load previously deposited shall be retrieved and operation continued as previously described to the medium-lift area where the load will be deposited. The truck will then be returned to the start area and shut off for 45 s to 60 s. This constitutes one cycle of the test course. Cycles shall continue until 200 h of operation have been completed. The trucks shall travel in alternate directions on alternate days, that is as described above on the first day and the second day traveling in a forward direction from the start position toward the medium lift area retrieving and depositing loads as required.

b. Operation Procedure for 80-h Test Course (Figure B2). Two 4000-lb loads "A" and "B" shall be positioned in Areas "X" and "Y" respectively. Start with truck facing Load "A" in Area "X." Drive truck forward until forks are fully engaged under Load "A." Pick up Load "A" to carry position, and back truck clear of Area "X." Execute a 90-degree turn such that truck is facing Area "Z." Proceed in a forward direction to Area "A." Place Load "A" at ground level in Area "Z." Back truck until forks are clear of Load "A," continue in a rearward direction to Area "Y." Execute a 90-degree turn such that truck is facing Load "B." Drive forward until forks are fully engaged under Load "B." Pick up Load "B" to carry position and back away from Area "Y." Execute a 90-degree turn such that truck is facing Area "Z." Proceed in a forward direction to Area "Z" and place Load "B" on top of Load "A." Back truck away from Load "B" until forks are clear. Lower forks to ground level. Raise forks sufficiently to engage Load "B" in Area "Z." Proceed in a forward direction until forks are fully engaged under Load "B." Pick up Load "B" and back away from Area "Z" until clear of Load "A." Lower forks to carry position. Proceed in a rearward direction to Area "Y." Execute 90-degree turn such that truck is facing Area "Y." Deposit Load "B" in Area "Y." Back truck away from Load "B" until forks are clear. Execute a 90-degree turn such that truck is facing Area "Z." Proceed in a forward direction to Area "Z." Fully engage forks under Load "A" and lift to carry position. Proceed in a rearward direction until truck is opposite Area "X." Execute a 90-degree turn such that truck is facing Area "X." Deposit load "A" into Area "X." Back truck away from Load "A" until forks are clear. Lower forks to ground level. This constitutes one complete cycle. Continue cycles until 80 h have elapsed (7 h/day). Forty hours shall be performed on a prepared hard stand surface, and 40 h on a nonprepared, stabilized surface.

APPENDIX C

CONVERTING A 400-LB LIFT TRUCK FROM GAS TO LPG ENGINE POWER

TASK: To convert a gasoline-engine-driven forklift truck to a liquid petroleum gas (LPG)-engine-driven forklift truck.

END ITEM: Truck, Lift, Fork, 4,000-lb Capacity, Solid-Tired, 180-in. Lift.

CONTRACT NO: DSA700-74-C-9020.

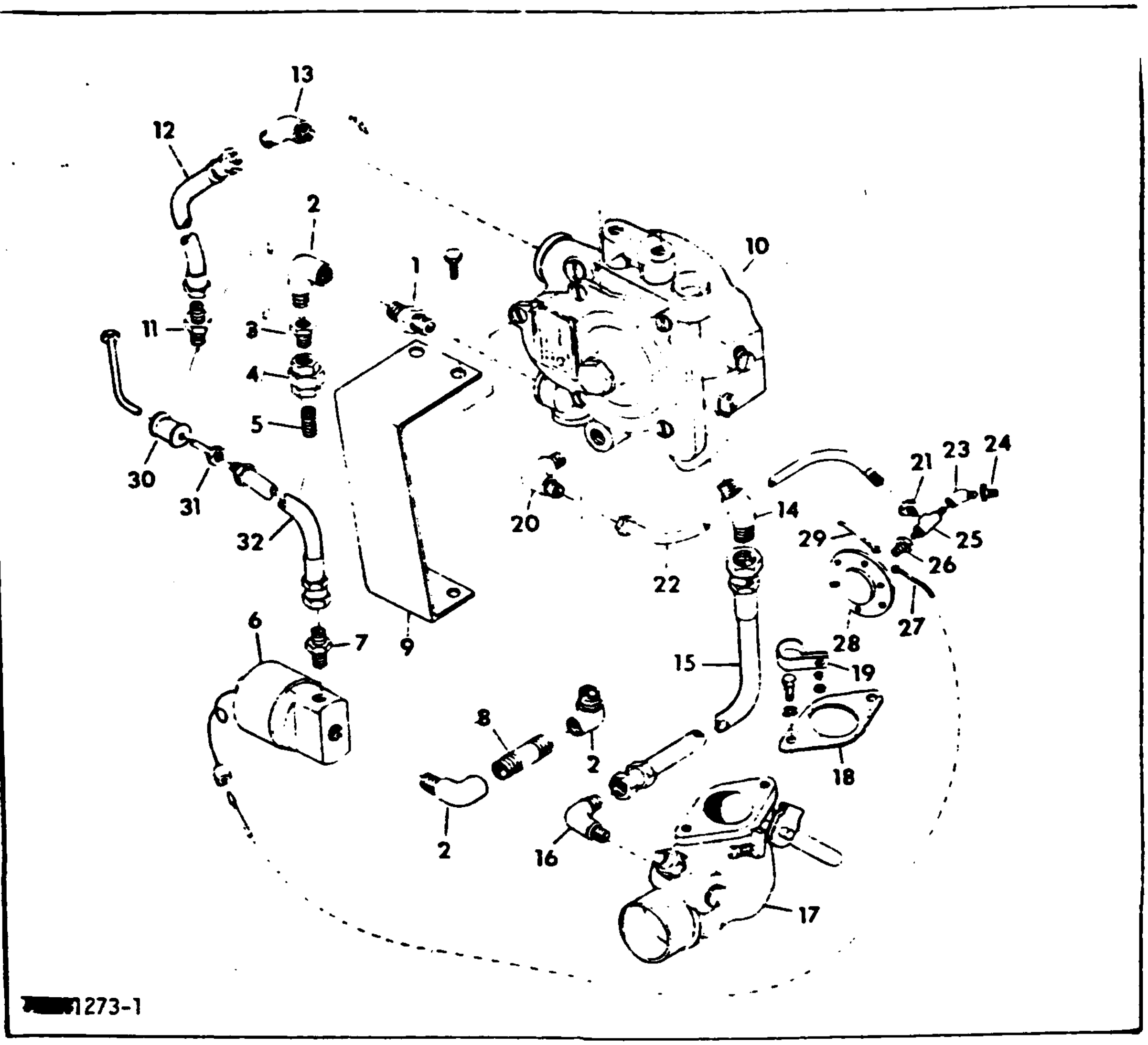
I. INTRODUCTION

1. One phase of the power source testing was to ascertain if a gasoline-engine-driven, military-adapted commercial forklift truck, procured using Military Specification MIL-T-52862, could be converted to LPG-engine-driven by installing a commercially available conversion kit. This kit was to be installed by utilizing available shop personnel (mechanics). This task, basically, was to procure and install the conversion kit. Testing procedures for this converted forklift truck are recorded in the text of the main report.

II. CONVERSION KIT PROCUREMENT

2. A purchase request was prepared and submitted for a commercially available kit to convert a continental F135 engine. A kit was ordered from Propane Carburetion Corp., Trenton, MI. However, installation for the kit was not included in the shipment. Attempts to obtain these kit installation instructions were unsuccessful. It was later learned that the kit shipped from Propane Carburetion Corp. was for a Continental Engine F163. Therefore, as the requisition called for a kit to fit a Continental Engine F135, the kit was returned to the company.

a. Another requisition was prepared to procure by "sole source," a conversion designed for the F135 Continental Engine by Allis-Chalmers and ordered from the local Allis-Chalmers dealer as Catalog Part No. 4851413-7. This kit was delivered with all parts, a detailed parts listing (Figures C1 through C4), and installation instructions. The cost of the kit, with two gas cylinders, was less than $400.



FUEL SYSTEM - LP GAS - BEAM
CATALOG NO. 4851413-7

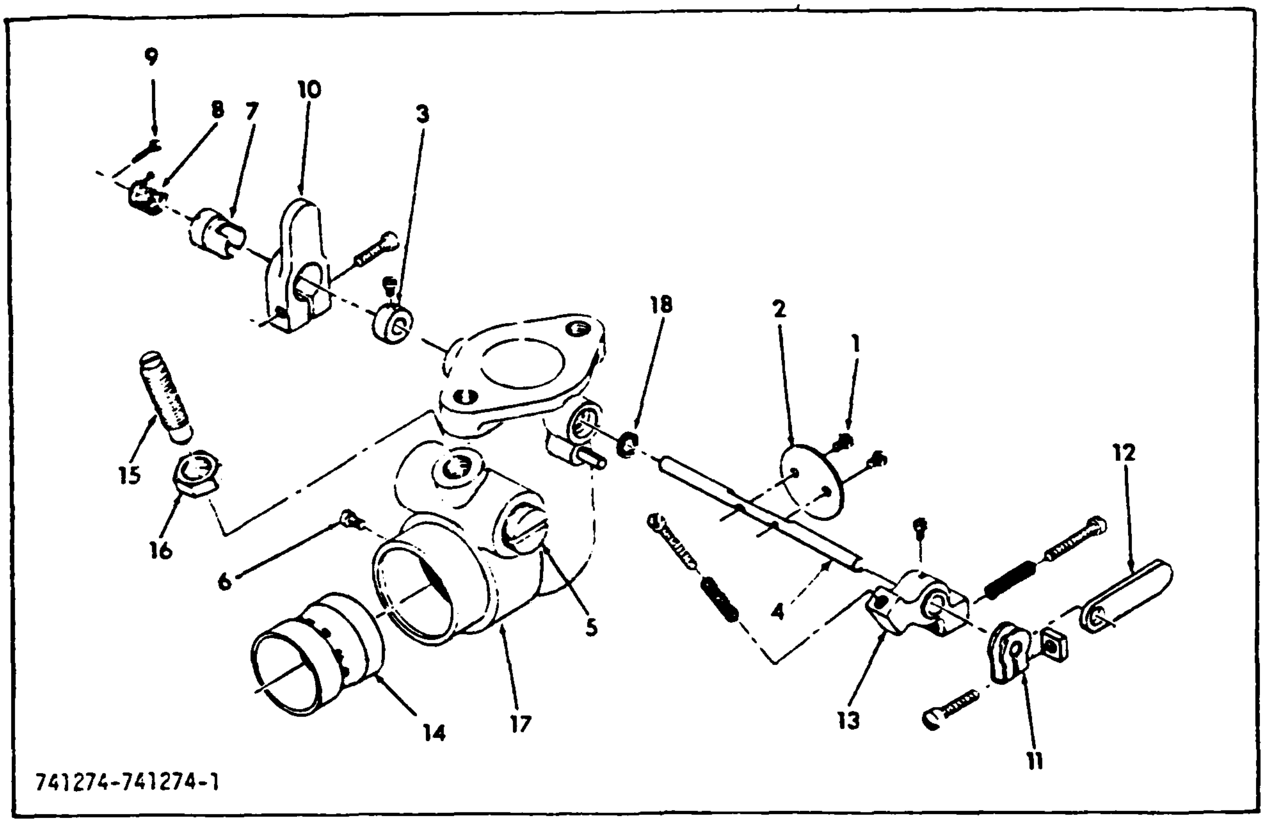
ITEM	PART NO.	DESCRIPTION	QTY.	
1	3917919-3	ADAPTER-BRASS-.25" -18 PT	1	
2	3918374-0	ELBOW-90° BRASS-.25"-18 PT	3	
3	3920556-8	CONNECTOR-BRASS-.38" PT-.25" PT	1	
4	3901732-8	UNION-.38" PT	1	
5	3917368-3	NIPPLE-CLOSE-BRASS-.38" X 1"	1	
6	4842318-0	LOCK-FUEL	1	
7	3912324-1	CONNECTOR-BRASS-.38" TUBE OD-.25" PT	1	
8	3917522-5	NIPPLE-BRASS-.25" PT X 1.5"	1	
9	4851406-1	BRACKET	1	
10	3999744-8	VAPORIZER	1	SEE PAGE 65.32.51.00.1
	3928138-7	SCREW-.25"-20 X .62"	2	
11	3919486-1	CONNECTOR-BRASS-.38" TUBE OD-.38" PT	1	
12	4835849-3	HOSE-.38" ID-7.5" LONG	1	
13	3921371-1	ELBOW-45° BRASS-.38" TUBE OD-.25" PT	1	
14	3927592-6	ELBOW-45° BRASS-.38" TUBE OD-.38" PT	1	
15	4851403-8	HOSE-16.6" LONG	1	
16	3917750-2	ELBOW-90° BRASS-.38" TUBE OD-.38" PT	1	

Figure C1. Fuel system—LP gas—beam.

FUEL SYSTEM - LP GAS - BEAM (CONTINUED)
CATALOG NO. 4851413-7

ITEM	PART NO.	DESCRIPTION	QTY	
17	4851404-6	CARBURETOR	1	SEE PAGE 65.32.01.00.1
	0923325-5	CAPSCREW-.31"-18 X .88"	2	
	0917356-8	LOCKWASHER-.31"	2	
18	4511719-9	GASKET	1	
19	4774455-2	CLAMP	1	
	0916965-7	LOCKWASHER-.38"	1	
	0916950-9	NUT-.38"-16	1	
20	0915399-0	ELBOW-90° BRASS-.12"-27 PT	1	
21	4908433-8	NIPPLE-HOSE-.12"	2	
22	4851405-3	HOSE-VACUUM-20" LONG	1	
23	0920655-8	ELBOW-45° BRASS-.12" PT	1	
24	0901834-2	BUSHING-BRASS-.25" PT X .12" PT	1	
25	0918960-6	TEE-BRASS-.12" PT	1	
26	0920215-1	NIPPLE-BRASS-.12"-27 PT	1	
27	4849319-1	WIRE-65"	1	
28	4751055-7	SWITCH-VACUUM	1	
29	4782605-2	WIRE-TO COIL-65"	1	
30	4830777-1	GROMMET	1	
31	4841623-4	TUBE-FUEL	1	ACC ONLY
32	4841625-9	HOSE-FUEL	1	ACC ONLY
	4835844-4	HOSE-FUEL	1	ACP ONLY
33	4255355-2	TY-RAP	2	NOT ILLUSTRATED

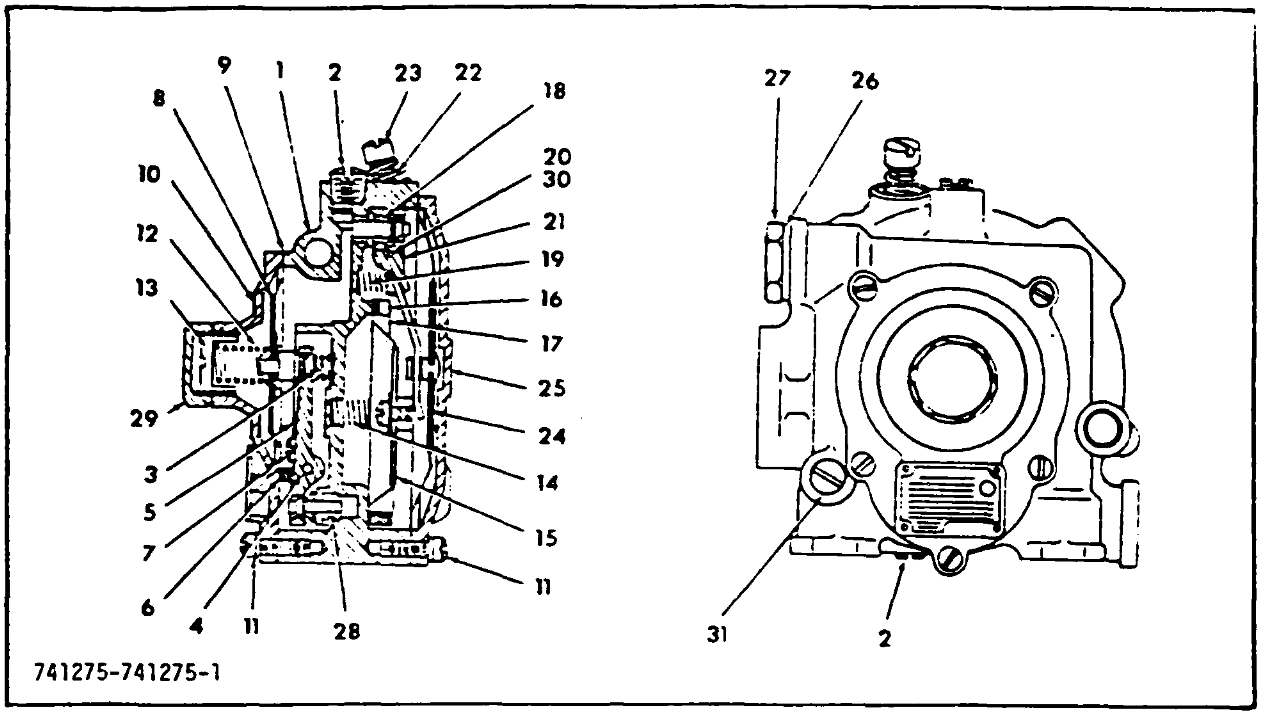
Figure C2. Fuel system—LP gas—beam.



CARBURETOR - BEAM - 4851404-6

ITEM	PART NO.	DESCRIPTION	QTY.	
1	0925712-2	SCREW-#6-32 X .25"	2	
2	4998930-4	VALVE-THROTTLE	1	
3	4998933-8	COLLAR-SHAFT	1	INCL SCREW
4	---------	SHAFT-THROTTLE	1	ORDER ASSY
5	0912091-6	PLUG-SLOTTED HD-.38" PT	1	
6	0906792-7	SCREW-#10-32 X .31"	1	
7	4908303-3	BUSHING-SPRING RETAINER	1	
8	4998934-6	SPRING-GOVERNOR CONTROL	1	
9	0918445-8	PIN-.06" X .5"	1	
10	---------	LEVER-GOVERNOR	1	ORDER ASSY
11	4045448-0	CLEVIS-.25"	1	INCL HARDWARE
12	---------	LEVER-FLOATING	1	ORDER ASSY
13	4998943-7	QUADRANT	1	INCL HARDWARE
14	---------	VENTURI	1	ORDER ASSY
15	4908305-8	SCREW-POWER ADJUST	1	
16	0919262-6	NUT-LOCK-.5"-20	1	
17	---------	BODY-CARBURETOR	1	ORDER ASSY
18	4908310-8	SEAL-THROTTLE SHAFT	1	

Figure C3. Carburetor—beam.



FUEL VAPORIZER - BEAM - 4999744-8

ITEM	PART NO.	DESCRIPTION	QTY.	
1	4908311-6	BODY-REGULATOR	1	
2	0917426-9	*#PLUG-.12" PT	2	
3	4908312-4	*#SPRING-PRIMARY LEVER	1	
4	0917723-9	*#PIN-.12" X 1"	1	
5	4908313-2	*#@LEVER-PRIMARY-WITH VALVE	1	
6	4908314-0	BRIDGE-PRIMARY LEVER	1	
7	0906792-7	*#SCREW-#10-32 X .31"	2	
8	4908315-7	*#@DIAPHRAGM-PRIMARY	1	INCL ITEM 9
9	4908316-5	GASKET-DIAPHRAGM	1	
10	4908317-3	COVER-PRIMARY REGULATOR	1	
11	0930436-1	*#@SCREW W/LOCKWASHER-#10-32 X .5"	10	
12	4908318-1	*#SPRING-PRIMARY PRESSURE	1	
13	4908319-9	RETAINER-ADJUSTABLE SPRING	1	
14	4908280-3	*#SPRING-VACUUM LOCK	1	
15	4908281-1	*#@DIAPHRAGM-VACUUM LOCK	1	
16	4908282-9	RING-VACUUM LOCK COVER	1	
17	0922121-9	*#SCREW-#10-32 X .38"	4	
18	4908283-7	#ORIFICE-SECONDARY REGULATOR	1	
19	4908284-5	*#SPRING-SECONDARY LEVER	1	
20	4908285-2	*#PIN-SECONDARY PIVOT	1	
21	4908286-0	*#@LEVER-SECONDARY WITH VALVE	1	
22	4992925-4	*#SPRING-IDLE ADJUSTMENT	1	
23	4908287-8	*#SCREW-IDLE ADJUSTMENT	1	
24	4908288-6	*#@DIAPHRAGM-SECONDARY	1	
25	4908289-4	COVER-SECONDARY REGULATOR	1	
26	4908290-2	#GASKET-PLUG	1	
27	4908291-0	#PLUG-RELIEF-.62"-18	1	
28	4908292-8	#ORIFICE-PRIMARY REGULATOR	1	
29	4908293-6	CAP-SPRING RETAINER	1	
30	0922707-5	*#SCREW-#10-32 X .25"	2	
31	0917335-2	*#PLUG-.12" PT	1	

*INCLUDED IN KIT 4908294-4
#INCLUDED IN KIT 4908295-1
@INCLUDED IN KIT 4908296-9

Figure C4. Fuel vaporizer—beam.

b. Installation Instructions–Beam LPG Kit.

(1) Drain gasoline tank.

(2) Run engine until it stops.

(3) Disconnect battery leads.

(4) If possible–the gasoline tank should be removed. If it is not removed it should be filled with non-combustible material that does not freeze if left out-of-doors.

(5) Drain radiator.

(6) Remove The Following:

(a) Fuel lines.

(b) Gasoline carburetor.

(c) Fuel pump.

(d) Gasoline gauge dash unit. Tape terminals on wires left by gauge removal.

(e) Water bypass and bypass fittings. If engine has no water bypass, an alternate procedure will be listed on the vaporizer assembly location drawing.

(f) Pipe plug from the intake manifold.

(g) Choke cable assembly.

(7) Install The Following:

(a) Fuel pump cover and gasket.

(b) Gasoline gauge cover (snap-in cover).

(c) Plug gasoline tank inlet and outlet opening if gasoline tank is not removed.

(d) Vaporizer solenoid assembly–per the attached drawing.

(e) Brass fittings provided for the thermostat housing and water pump. Face fittings towards vaporizer assembly, if bypass was removed.

(f) Vacuum switch with fittings provided in the intake manifold, if not installed on vaporizer assembly; vacuum hose regulator to manifold.

(g) Wire: (1) Vacuum switch in series with ignition switch side of coil–Propane solenoid.

(h) Propane carburetor.

(i) Water lines from water fitting closest to propane solenoid to thermostat housing; from remaining fitting to water pump. Clamp or tape where necessary. If regulator is mounted so that one water fitting is higher than the other–the hose hook-up will be as follows: Thermostat housing to lower fitting and water pump to upper fitting.

(j) Carburetor hose from vaporizer to carburetor.

(k) Bulkhead fitting relief valve assembly per the attached drawing. Relief valve should be vented outside of truck.

(l) Auxiliary fuel line from the propane solenoid to the bottom of bulkhead assembly. Clamp where necessary.

(m) Main fuel line from the top of the bulkhead assembly to the fuel cylinder.

(n) Cylinder brackets per the attached drawing.

(o) Attach battery cables and fill radiator.

(p) With fuel cylinder valve turned on–energize the propane solenoid and check the system for leaks–using a soap solution. Most liquid detergents mixed with water will do.

(8) Run and adjust per adjustment instructions as follows:

Once the engine is running and has heated up to operating temperatures, the idle and power adjustments should be made. The idle screw is at the top of the unit. Adjust for smoothest idle or highest vacuum by turning in for rich, and out for lean. Power adjustment is on the carburetor. Power adjustment is made by turning the power screw in for lean and out for rich. If an exhaust analyzer is available, it is good practice to check the final adjustments. Power reading should be set at 13.0 or 13.2 air fuel ratio on the gasoline scale.

III. CONVERSION KIT INSTALLATION

3. Using the instructions furnished with the kit, installation proceeded as follows with comments shown in (00) paragraphs after each task:

a. Drain gas tank; run engine until it stops (Figure C5).

b. Disconnect battery.

c. Drain radiator (Figure C6).

d. Remove fuel lines.

e. Remove carburetor. (Figure C7).

f. Remove fuel pump.

g. Remove gasoline gauge from dash and tape wire ends (Figure C8).

h. Remove water bypass hose and fittings (Figure C9).

i. Remove pipe plug from head (Figure C10).

j. Install fuel pump cover and gasket.

k. Install Vaporizer Solenoid Assembly (Figure C11).

(1) The bracket on the vaporizer solenoid assembly was too short to reach the block. A spacer (Figure C12) was fabricated in the shop to correctly mate the vaporizer assembly to the engine block.

(2) The water hose would not fit back in place due to the position of the solenoid. The solenoid had to be repositioned and replaced using a shorter nipple.

(3) Directions to install the vaporizer solenoid assembly should be clearer and labeled drawings would benefit the installer. Fittings should be designated rather than described "e.g. Fitting closest to Solenoid."

(4) Most fittings have to be turned to align with the mating fitting.

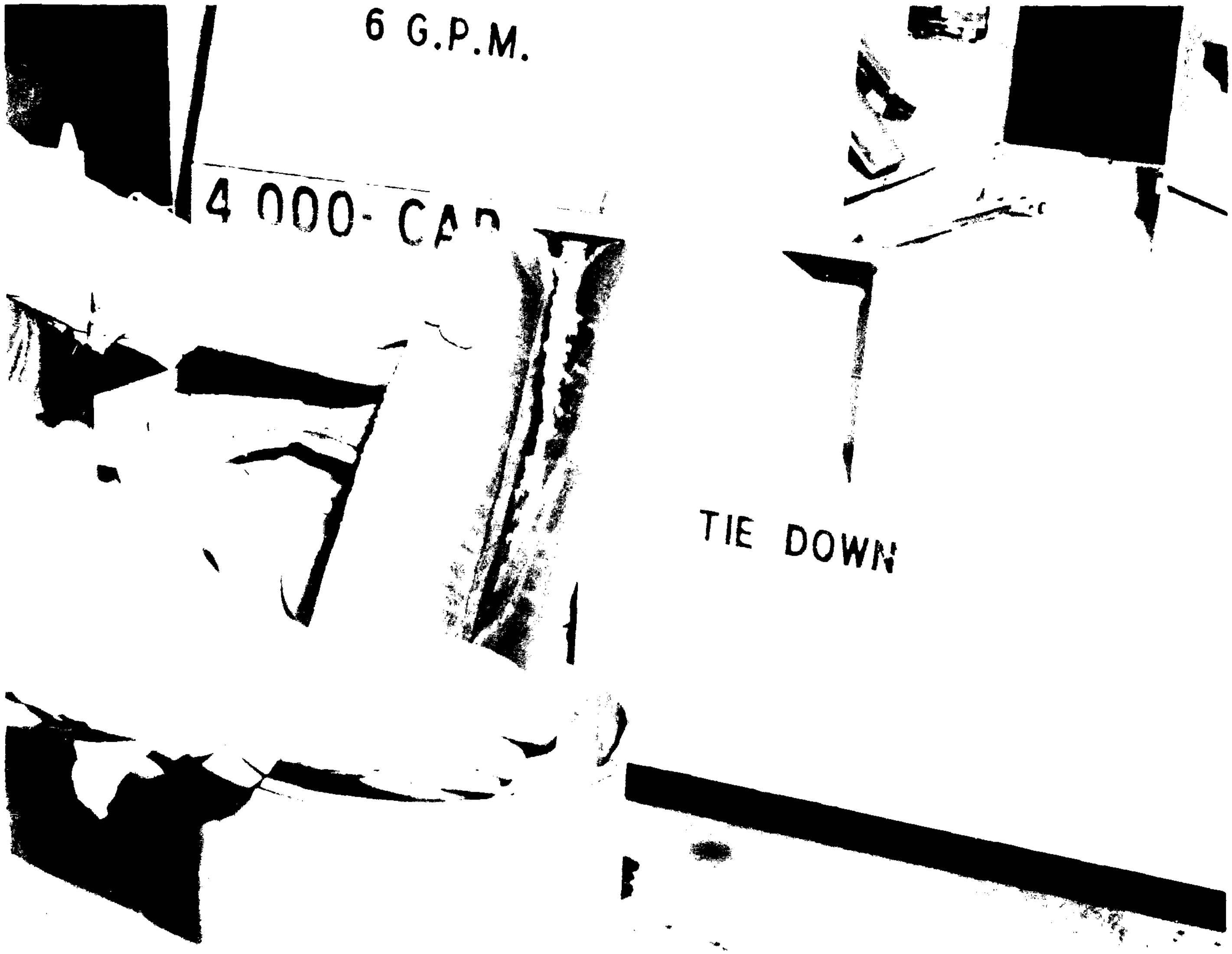


Figure C5. Draining gas tank.

Figure C6. Draining radiator.

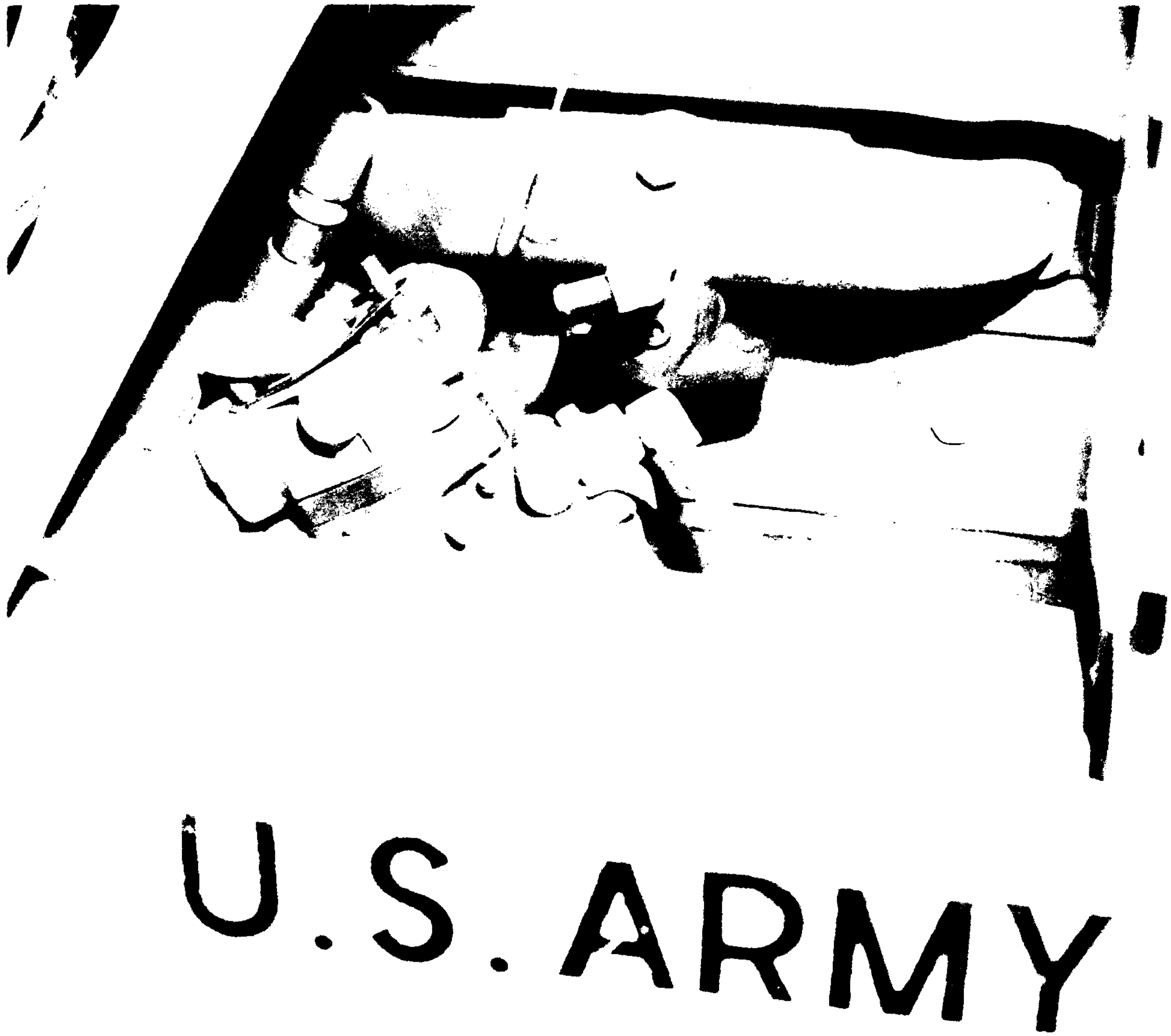


Figure C7. Removing carburetor.

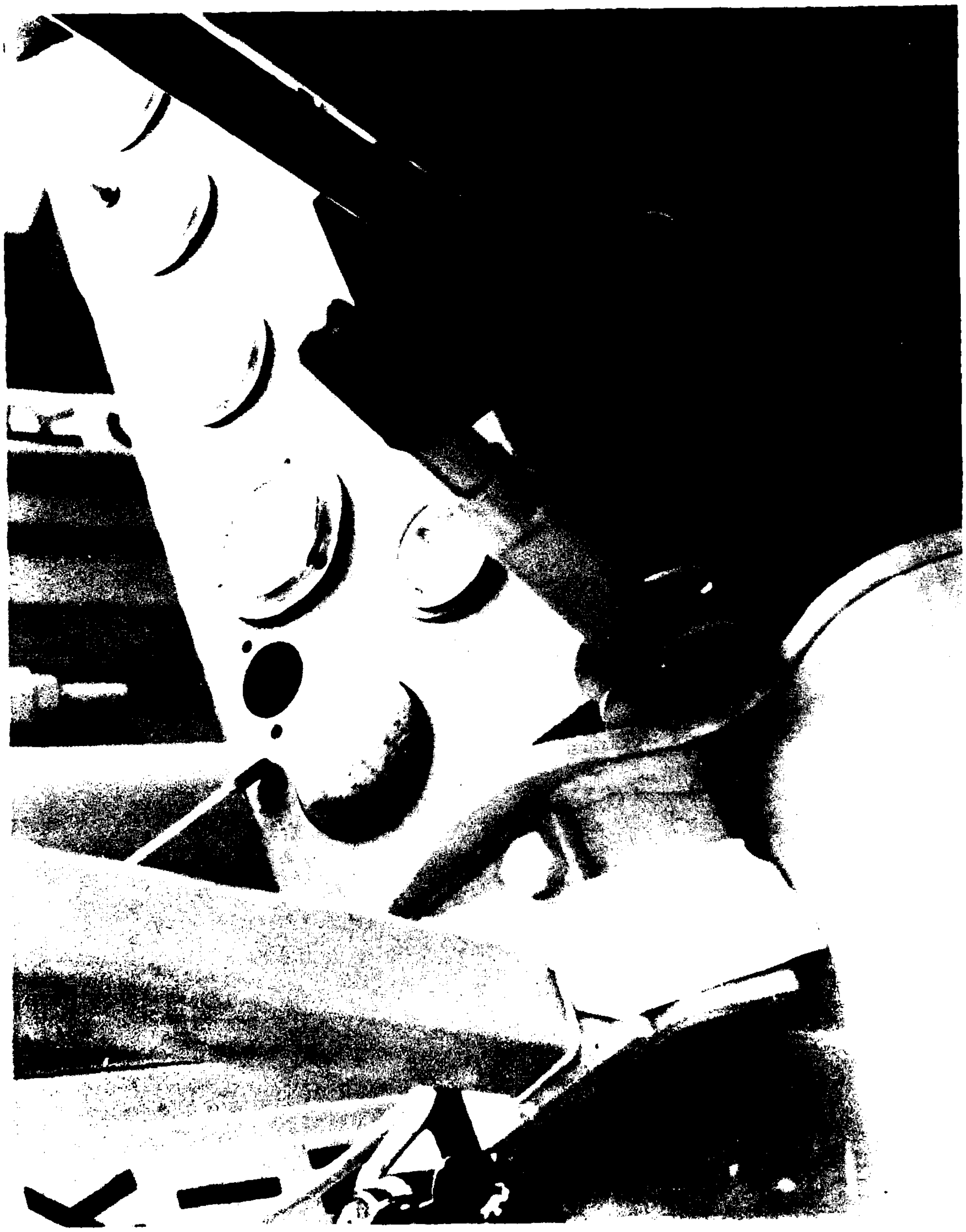


Figure C8. Gasoline gauge removed from dash.

Figure C9. Water bypass hose and fittings.

Figure C10. Pipe plug removed from head.

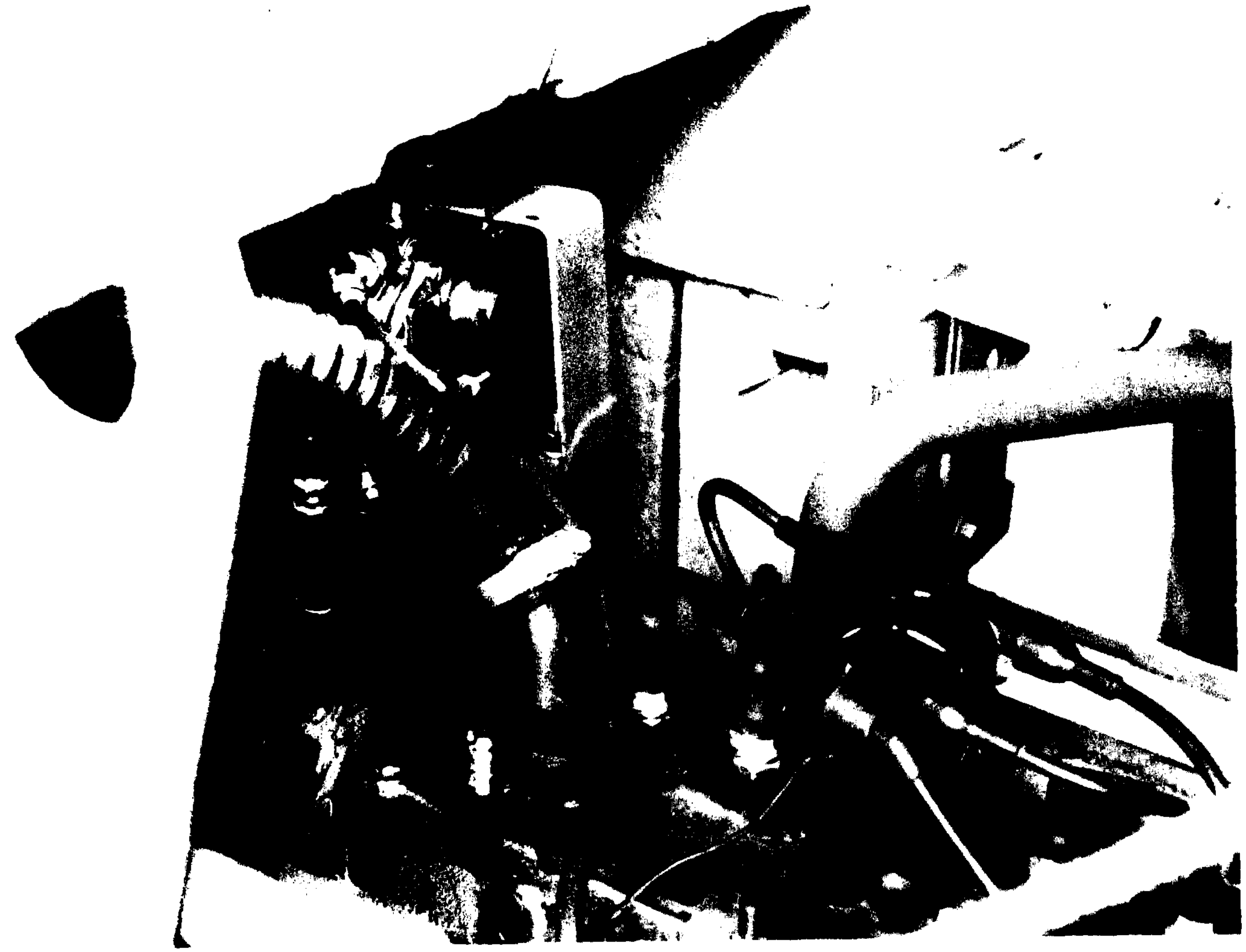


Figure C11. Vaporizer solenoid assembly installed.

Figure C12. Fabricated spacer for mating vaporizer to the engine block.

l. Install vacuum switch: Wire the switch to the positive side of the coil and to the propane solenoid (Figure C13).

m. Install the propane carburetor (Figure C14).

(1) The engine governor on top of the new carburetor will not fit back in place due to the shaft through the carburetor which hits the engine block. This shaft has a lever for gear-driven governors which this engine does not have. This engine has a vacuum governor. The shaft on this carburetor was cut off.

(2) The fitting for the hose connection to the vaporizer solenoid is located on the engine side of the carburetor. There is not enough room to connect the hose between the engine and the carburetor.

(3) Reverse fittings on the carburetor putting hose connection outside of the carburetor.

(4) The hose furnished with the kit is not long enough to connect the carburetor to the vaporizer solenoid assembly. A longer hose or extended fittings are needed.

n. Remove stop light to install gas cylinder mounting plate.

o. Bolts in kit to attach/mount the cylinder mounting plate to the truck counterweight should be 1½- to 2-in. longer (Figure C15).

p. The adjustment screw on the vaporizer solenoid assembly should be turned almost completely in before attempting to start the engine after the kit has been installed.

4. Installation Time. With the exception of making or fitting a spacer onto the vaporizer solenoid assembly, a mechanic, following instructions as furnished with the kit, installed the kit in 2 h (Figure C16).

5. Observations. It is necessary that the step by step instructions furnished with the LPG conversion kit be changed to put the propane carburetor on before putting on the vacuum switch, i.e., step h before step e.

6. Conclusions. With the noted observations, an Army 4000-lb gasoline-powered forklift can be converted to use LPG by one mechanic in approximately 2 manhours. The kit for such a conversion costs approximately $400 each without a quantity discount.

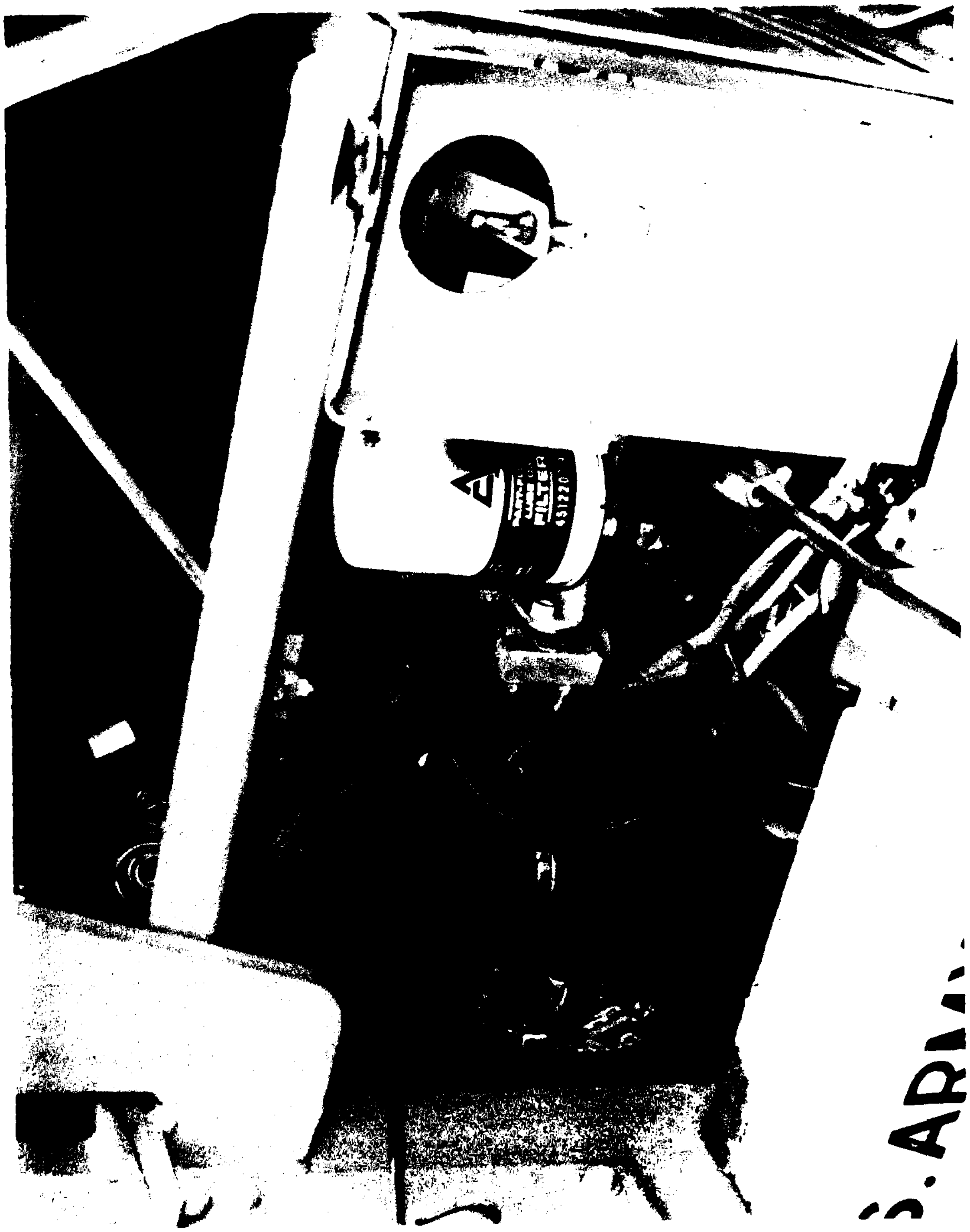


Figure C13. Vacuum switch.

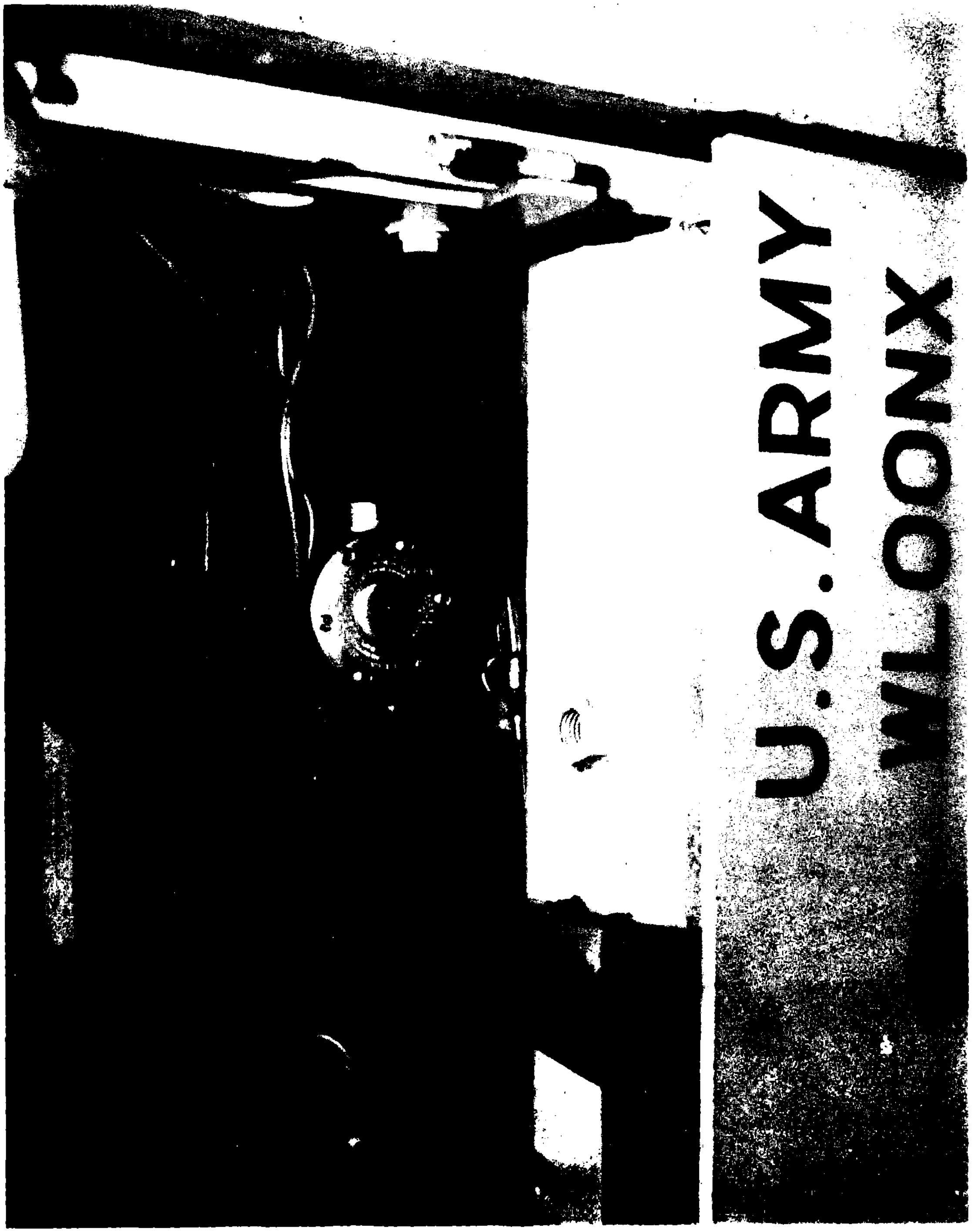


Figure C14. Propane carburetor.

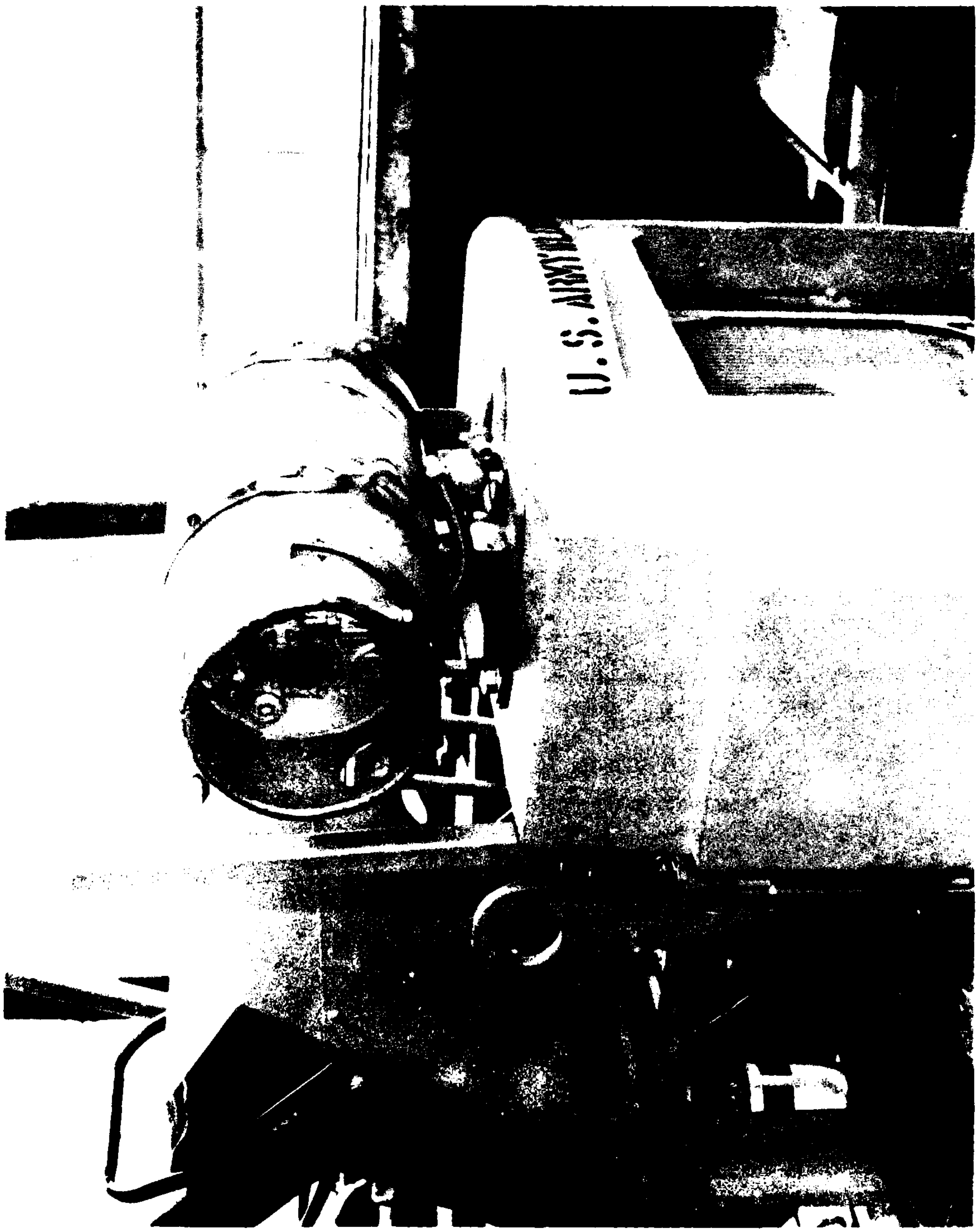


Figure C15. Cylinder mounting plate mounted to the truck counterweight with long bolts.

LPG KIT

MAJOR COMPONENTS

(1) LPG Tank

(2) Vaporizer-Regulator

(3) Vacuum Switch

(4) Solenoid Valve

(5) LPG Carburetor

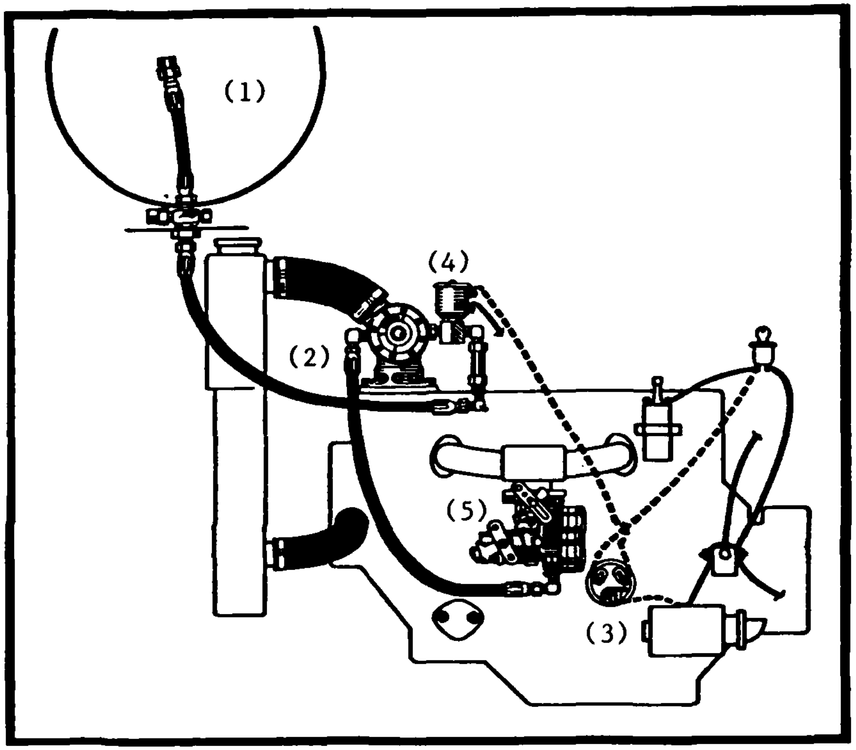


Figure C16. LPG kit.

APPENDIX D

EXHAUST EMISSION ANALYSIS OF FORKLIFT TRUCKS

1. **Introduction.** This appendix presents the results and analysis of examining the exhaust emissions of five lift trucks from the same manufacturer. The lift trucks were identical except for their power source. Figure 3 is powered by LPG and will be referred to in this appendix as lift truck No. 91. Figure 2 is gasoline powered and will be referred to as No. 92. Figure 1 is gasoline powered and will be referred to as No. 94. Figure 1A is LPG powered and will be referred to as No. 95. Figure 5 is diesel powered and will be referred to as No. 106.

The investigation was structured to consider emission differences not only between the various power sources but also the rates at which their emission products build up in an unventilated area such as an ammunition magazine/igloo. Although safety regulations (TM-9-1300-206 and AMCR 385-100) governing ammunition handling prohibit the use of all internal combustion-powered MHE inside magazines/igloos, it is known that in any contingency they will be used. Therefore, it is of importance that the relative merits of the various power alternatives be understood from an emission aspect.

2. **Background.** Engine exhaust emissions consist of both a gaseous and particulate component. Only the gaseous emissions of the engine exhaust are investigated in this analysis because particulates are considered significant only for diesel-engine emissions. Since only one diesel engine is included in this comparative analysis, diesel particulates were not considered. Sulfur dioxide (SO_2), which is a gaseous emission component, is not included in the analysis because it is also generally considered significant only for diesel emissions. This is because diesel fuel has a much higher sulfur content than gasoline.

Exhaust emissions of concern are products of engine combustion that are hazardous to human health. The primary products that are of interest are hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx). Table D1 presents the concentrations of these emission products allowed by the Surgeon General.

HC and CO emissions are formed due to incomplete combustion of fuel which is made up of carbon and hydrogen such as gasoline (C_8H_{18}) diesel fuel ($C_{18}H_{38}$) or liquid propane gas. (C_3H_8).[1] Some of the fuel exits the engine as a vapor (HC) and the remainder of the carbon in the fuel reacts with oxygen to form CO and CO_2. The nitrogen oxides are formed when the nitrogen in the combustion air, which is about 80 percent nitrogen, reacts with oxygen at the very high temperatures in the engine. Nitrogen is inert at low

[1] Automotive Emission Control, William H. Crouse and Donald L. Anglin.

Table D1. Maximum Allowable Level of Contaminants Permitted in a Working Environment

Emission Product	Level–PPM[2]
CO	50
CO_2	5000
NO	25
NO_2	5
HC	(See Note 3)

NOTES:

1. Selected list of contaminatns taken from Chapter XVII, 1910.1000, Subpart Z–Toxic and Hazardous Substances, Occupational safety and health administration regulation (accepted by the U.S. Army Surgeon General).
2. Parts per million–8-h, time-weighted average.
3. Hydrocarbon (HC) emission is composed of a combination of elements for which the referenced document gives allowable limits.

temperatures and will not readily combine with anything but combines with oxygen at high temperatures to form NOx.[2] Nitric Oxide (NO) and small amounts of nitrogen dioxide (NO_2) are the oxides of nitrogen most commonly found in vehicle emissions so the symbol for NO is used in the remainder of this appendix to indicate all oxides of nitrogen present. CO is considered to be the most hazardous engine emission since it is a colorless and odorless gas that is fatal to humans in high concentrations for long exposures. Emissions of HC, which are essentially non-toxic, and NO, which can be toxic in certain forms, are of concern mainly when the two combine in the presence of sunlight to form photochemical smog. Photochemical smog can cause irritation of the eyes, nose, and throat as well as respiratory problems.

3. **Test Procedures.** The emission tests of the forklift trucks were conducted in a test cell that was 7500 ft^3 in size. Exhaust gas emissions of HC were measured with a Beckman Model 402 Hydrocarbon Analyzer, NO with a Beckman Model 951 NO/NOx Analyzer, and oxygen, carbon dioxide and carbon monoxide with a Beckman Model 315B infrared analyzer (Figure D1). Emission tests were conducted at the start of the test program for each truck and at 100, 200, and 280 engine-h.

Exhaust gas emissions of CO, CO_2, NO, O_2, and HC were measured at 5-min intervals for 30 min in three different test modes. Test modes 1 and 3 began at start (time zero) of a cold engine which was then allowed to idle for the duration of the test. For Mode 1, the emission sensing probe was placed at a location in the test cell to obtain a representative sample (Figure D2). A circulating fan was used in the cell during the test to uniformly mix the atmosphere. For Mode 2, the throttle of the engine was propped open to the maximum governed speed, after an initial warm-up period, and the sensing probe was located as in Mode 1. For Mode 3, the sensing probe was inserted in the exhaust pipe of the engine (Figure D3). The test chamber exhaust fan was on during Mode 3 to provide open-air conditions. The exhaust fan was used to thoroughly exhaust the air in the test chamber between tests and after the warm-up period for test Mode 2.

4. **Results and Discussion (See also Figures D4 through D14).** The notes on the average graphs indicating that some curves have been omitted from the average are due to test results that differed from other tests on the same truck by such a large factor that either equipment malfunction was suspected or some other variable was present that affected the results for that test. Some of the variables that can affect engine emissions, that were not controlled during the testing, are the ambient temperature, barometric pressure, and humidity. The average graphs were drawn by averaging the data points from each test for a particular truck while omitting any test curve from those averaged that was so different from the other curves that the average would be biased.

[2] Ibid.

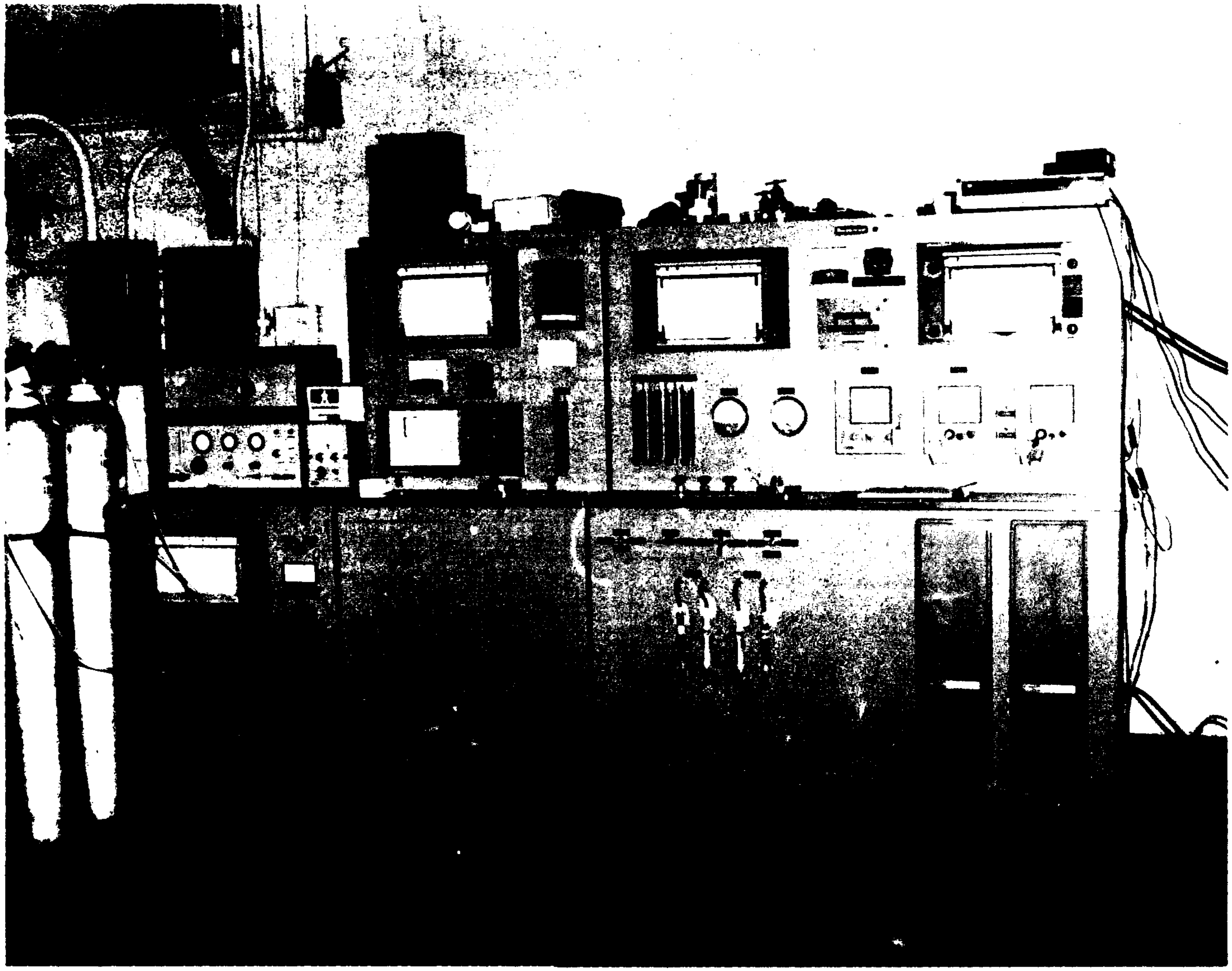
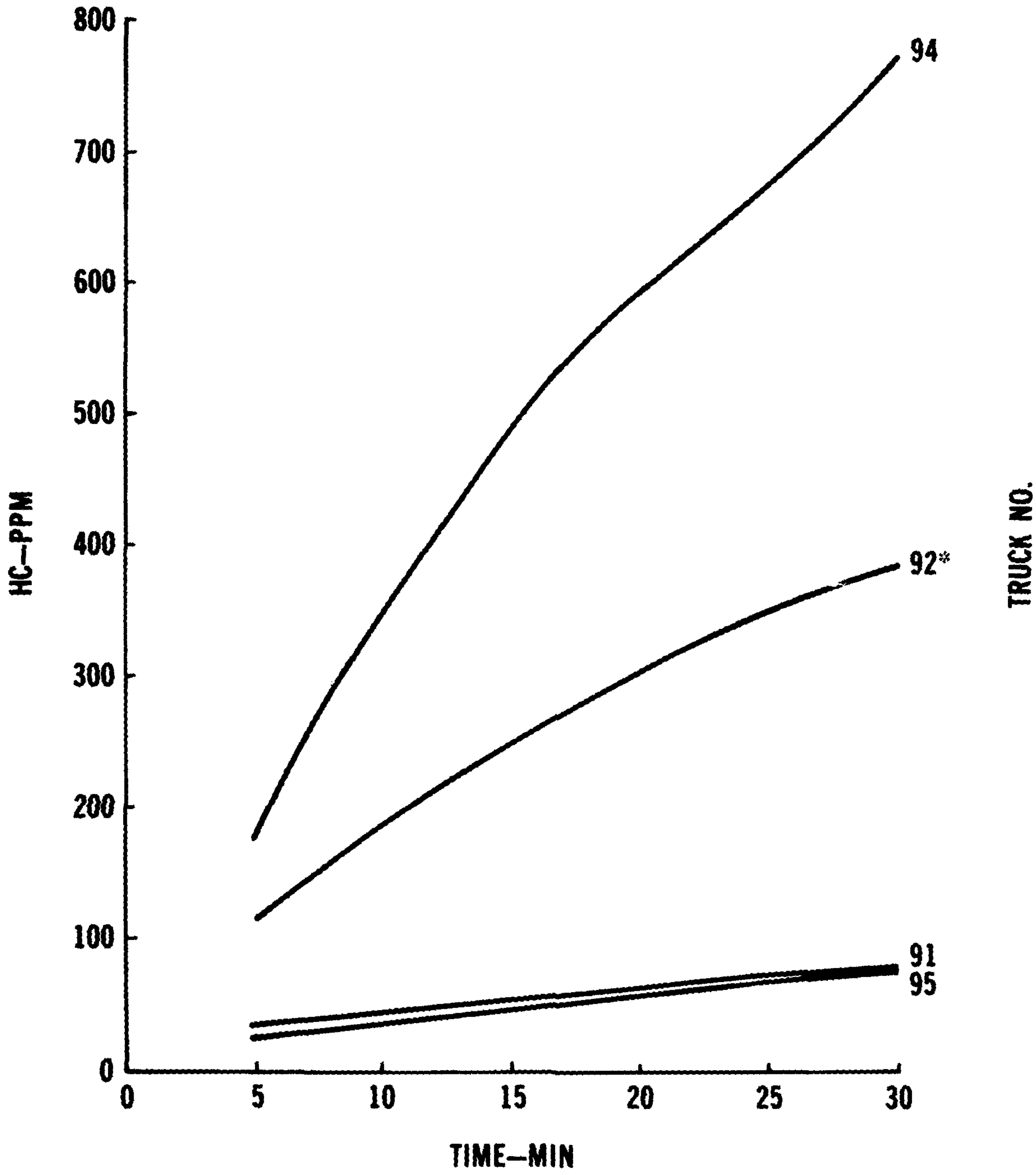


Figure D1. MERADCOM exhaust gas emission analyzer.

Figure D2. Exhaust sensor—positioned for sampling ambient air within test chamber.

Figure D3. Exhaust sensor—positioned for sampling direct exhaust.



91—162 CID—LPG
92—162 CID—GASOLINE
94—135 CID—GASOLINE
95—135 CID—LPG

*DEC 80 OMITTED

Figure D4. Average—room sample—idle.

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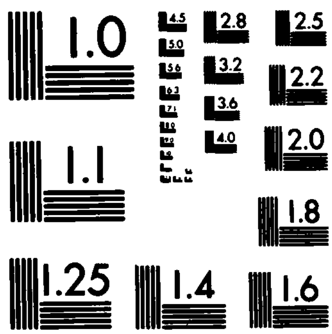


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

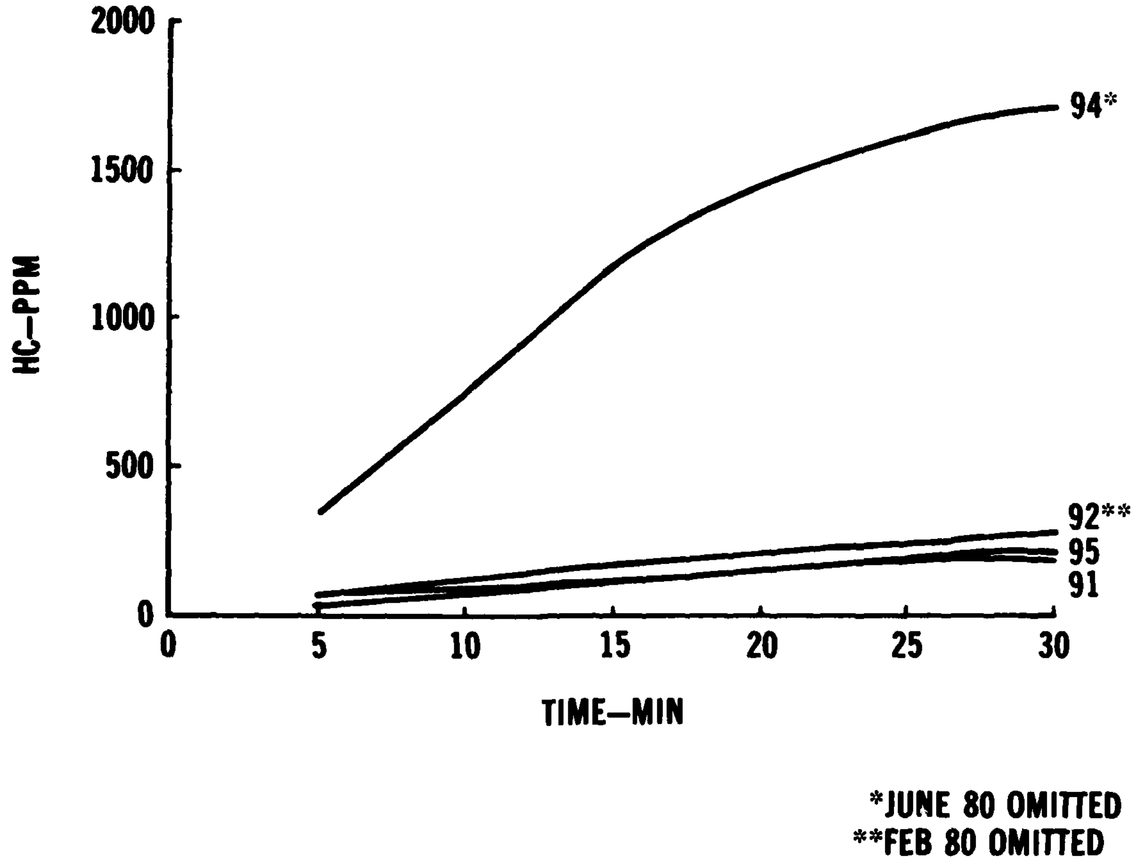


Figure D5. Average—room sample—WOT.

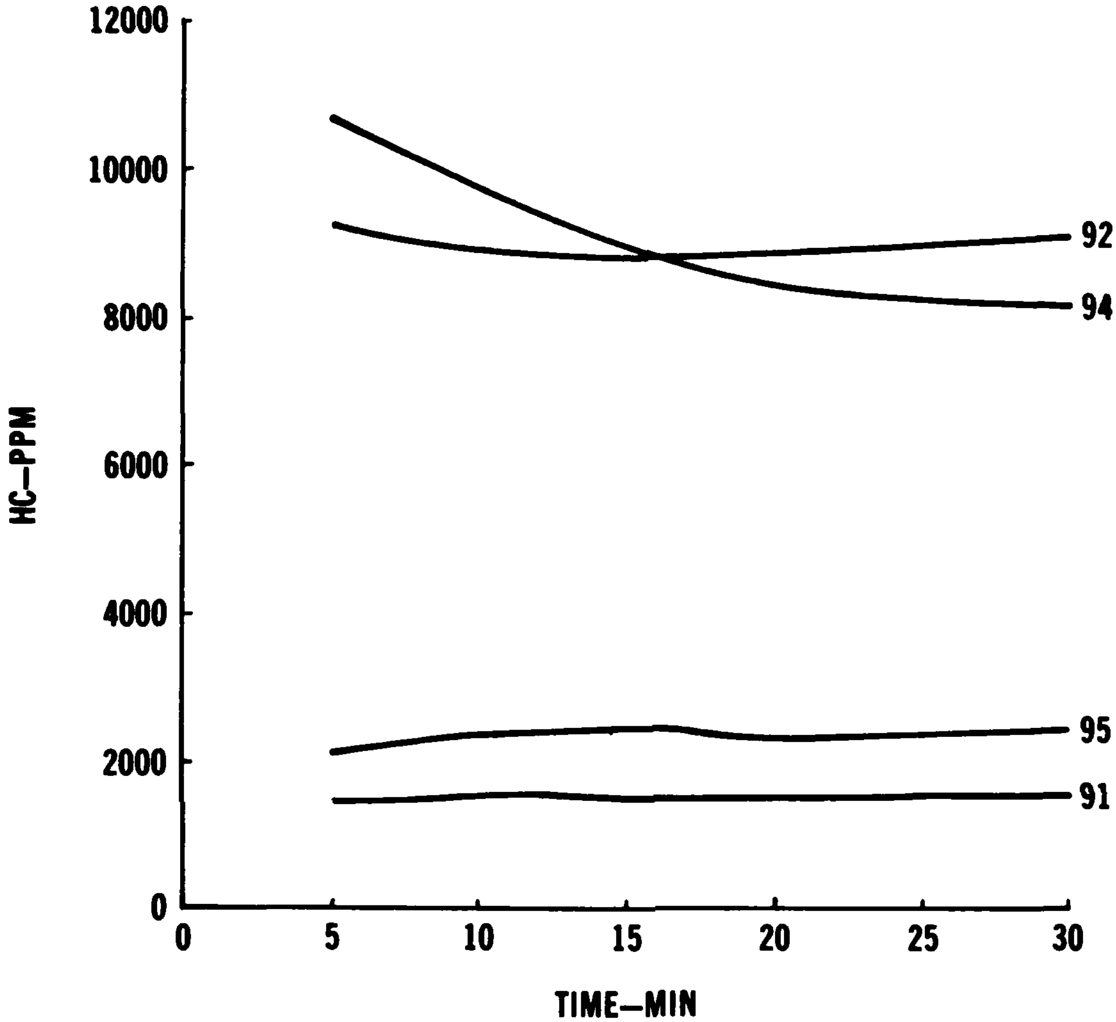


Figure D6. Average—direct exhaust—idle.

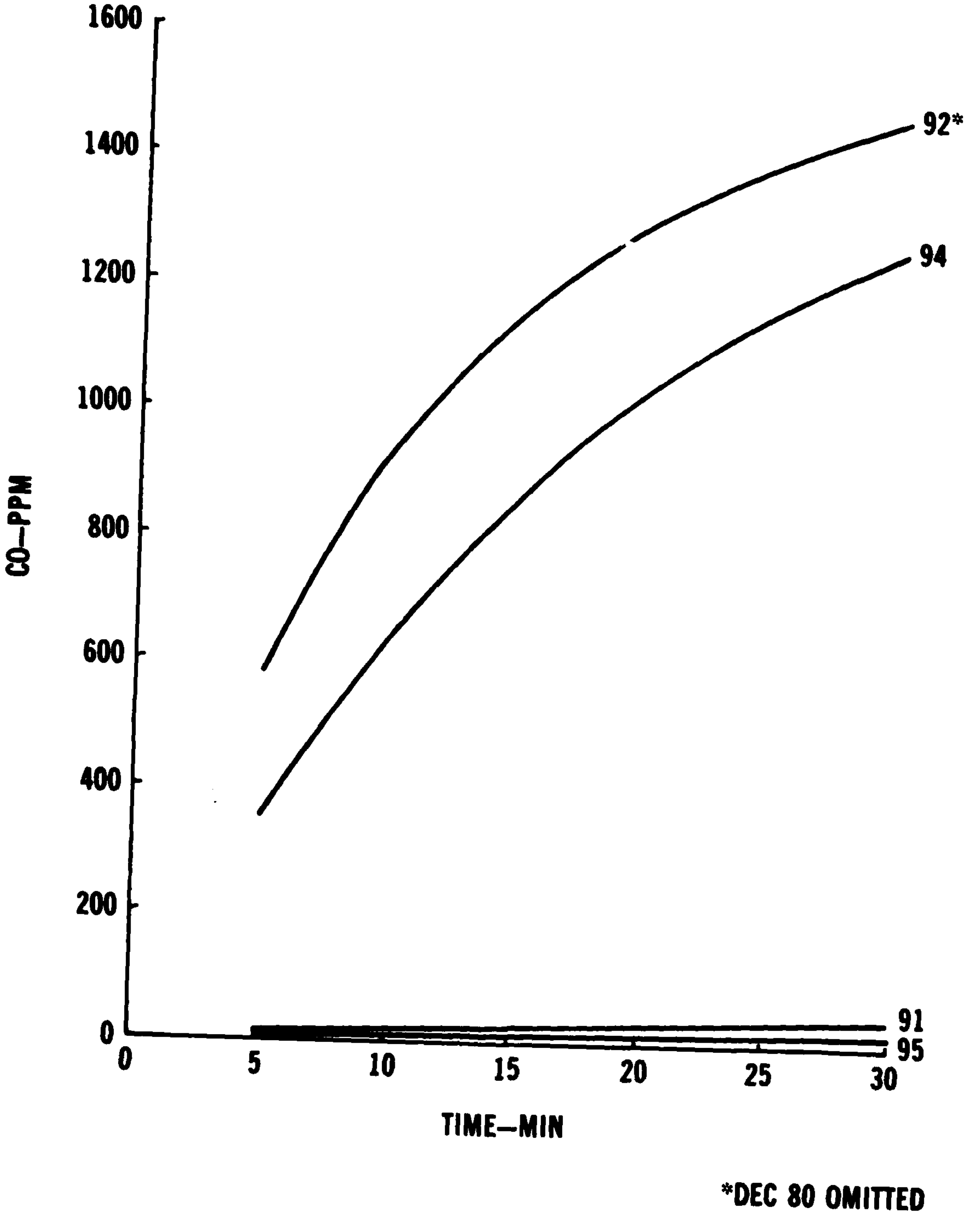


Figure D7. Average—room sample—idle.

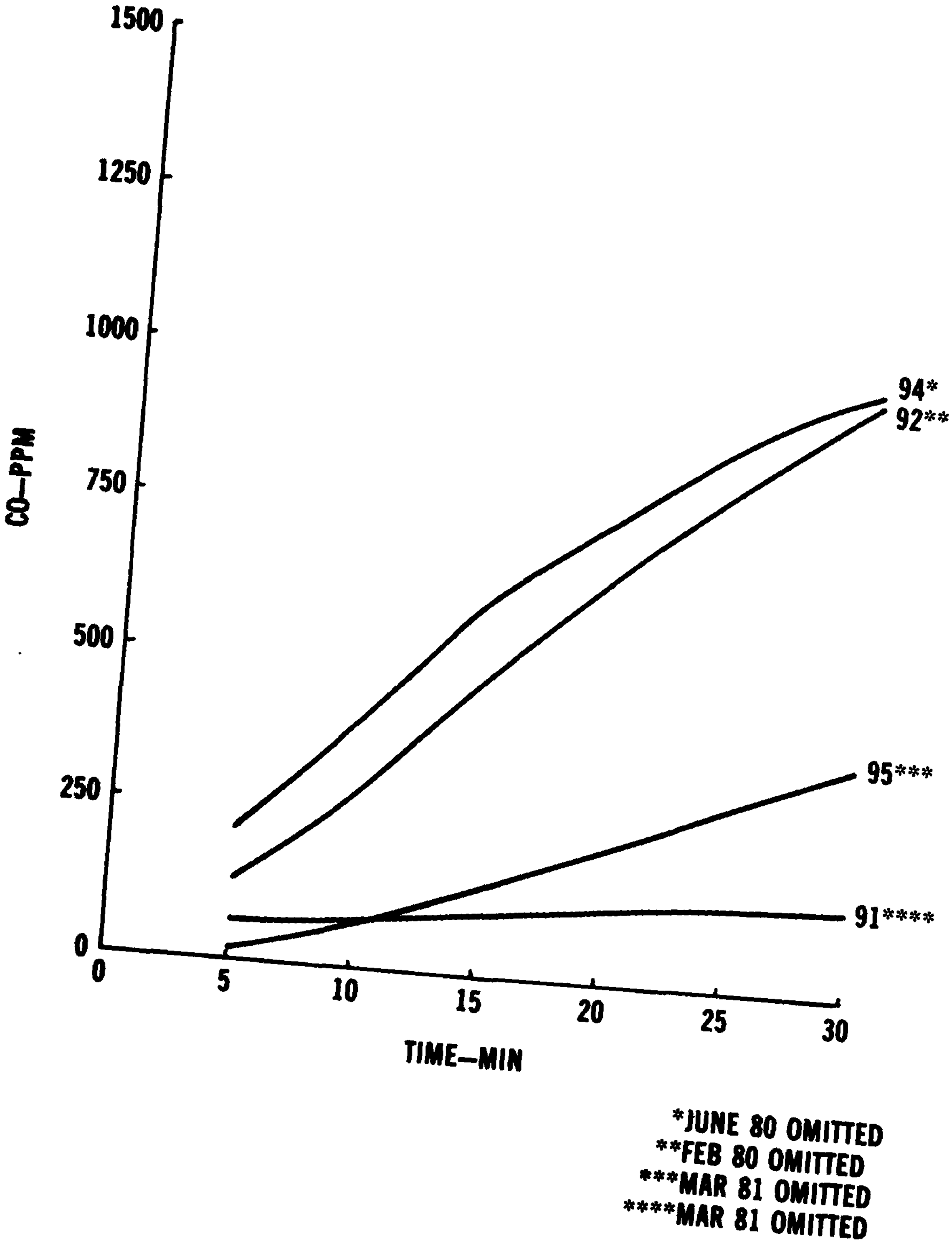
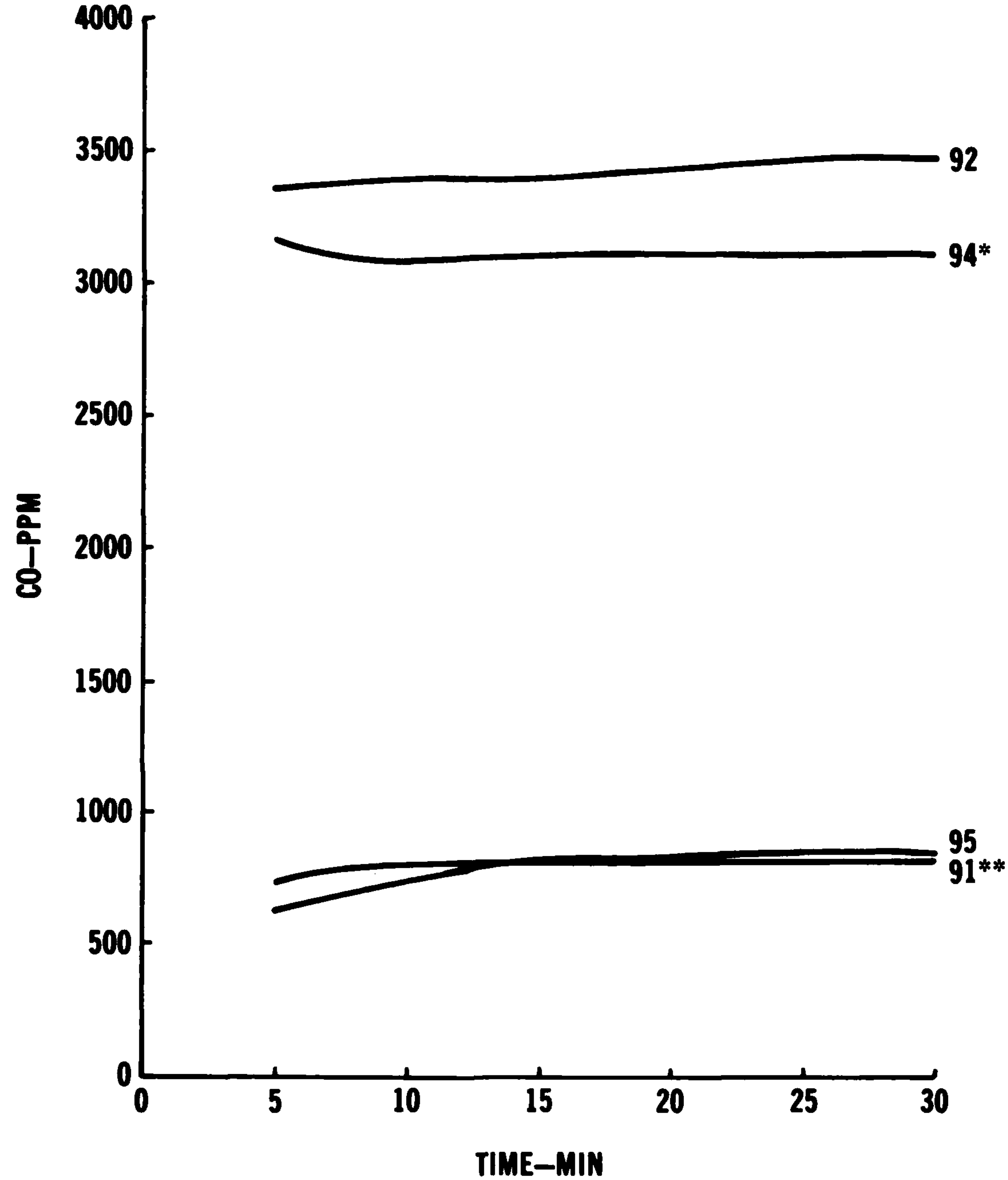


Figure D8. Average—room—WOT.



*FEB 80 OMITTED
**FEB 80 OMITTED

Figure D9. Average—direct exhaust—idle.

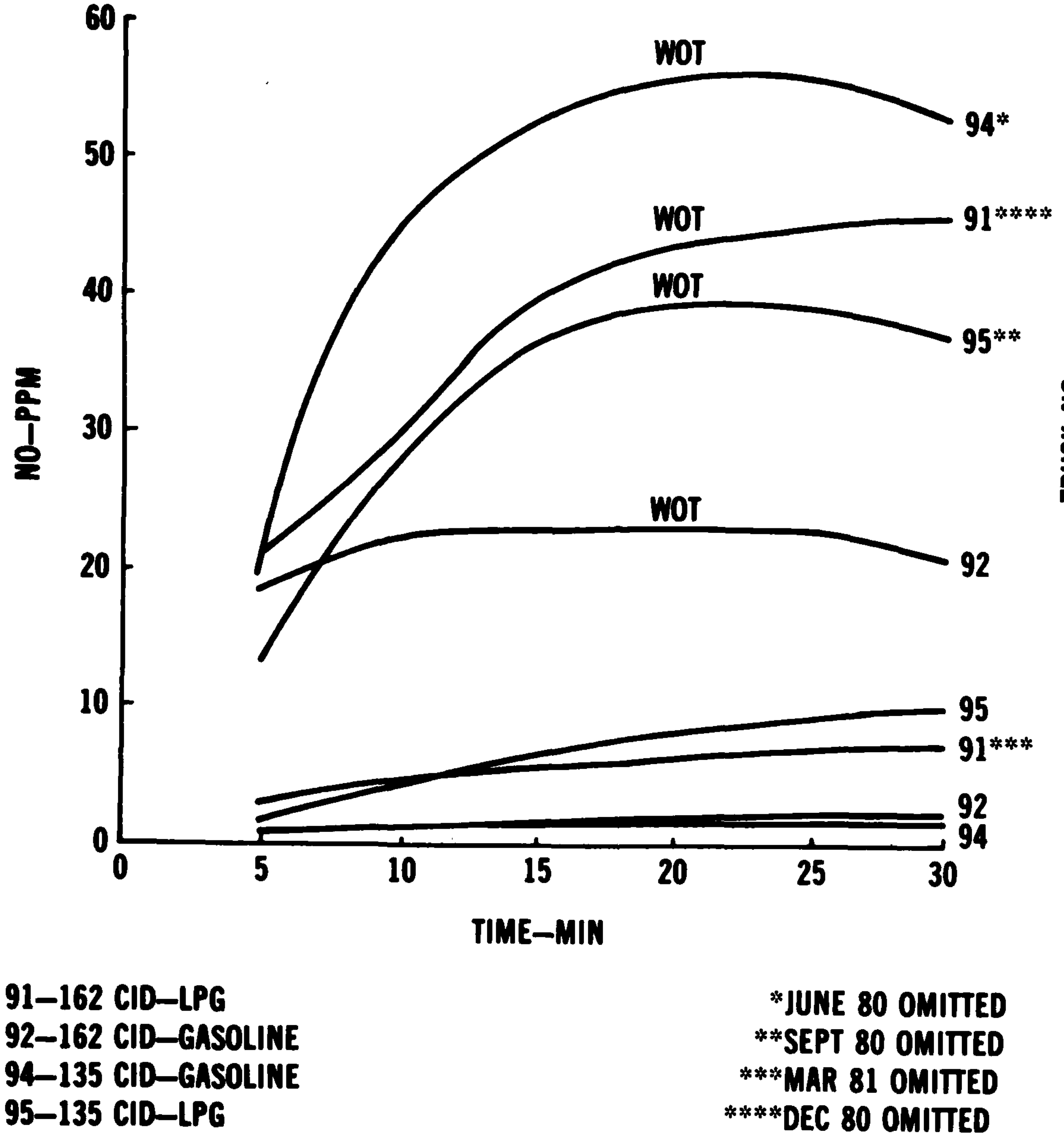
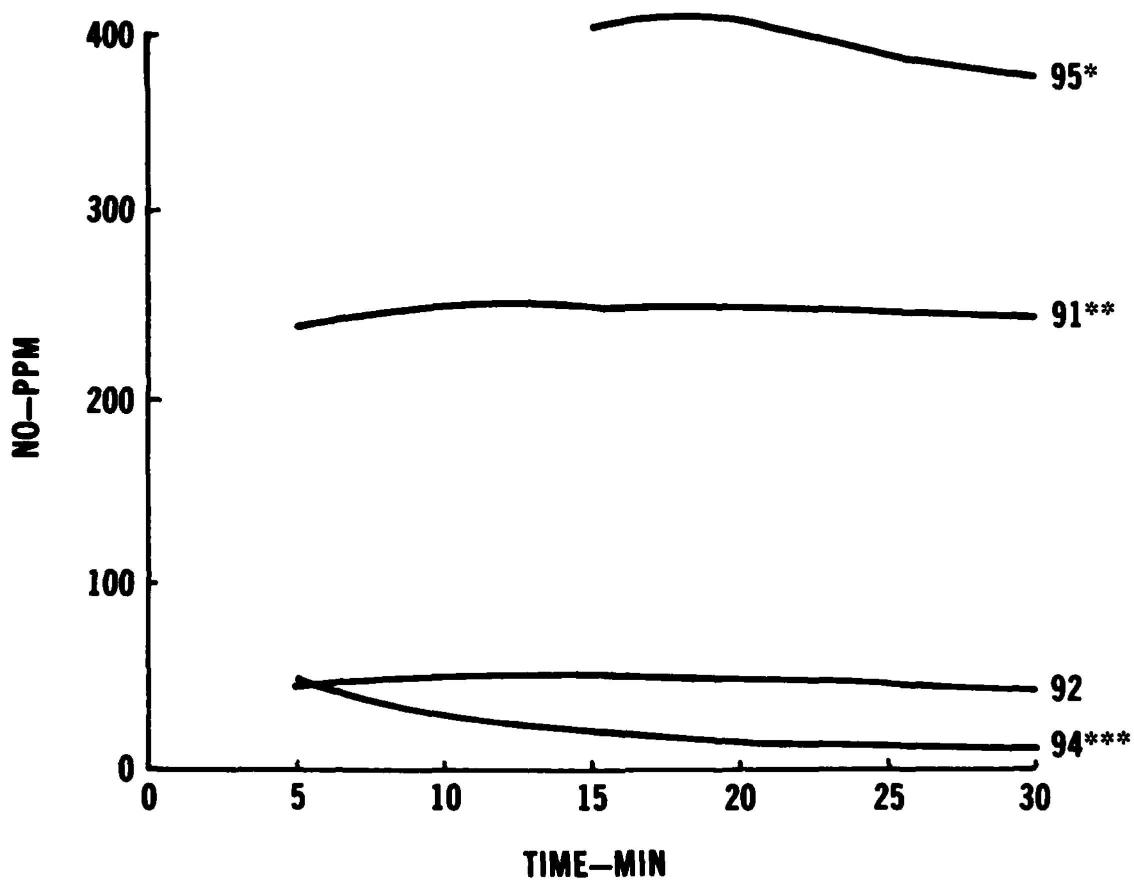


Figure D10. Average—room sample—idle and WOT.



*DATA NOT SUFFICIENT FOR AV. BEFORE 15 MIN.
**DEC 80 OMITTED
***SEPT 80 OMITTED

Figure D11. Average—direct exhaust—idle.

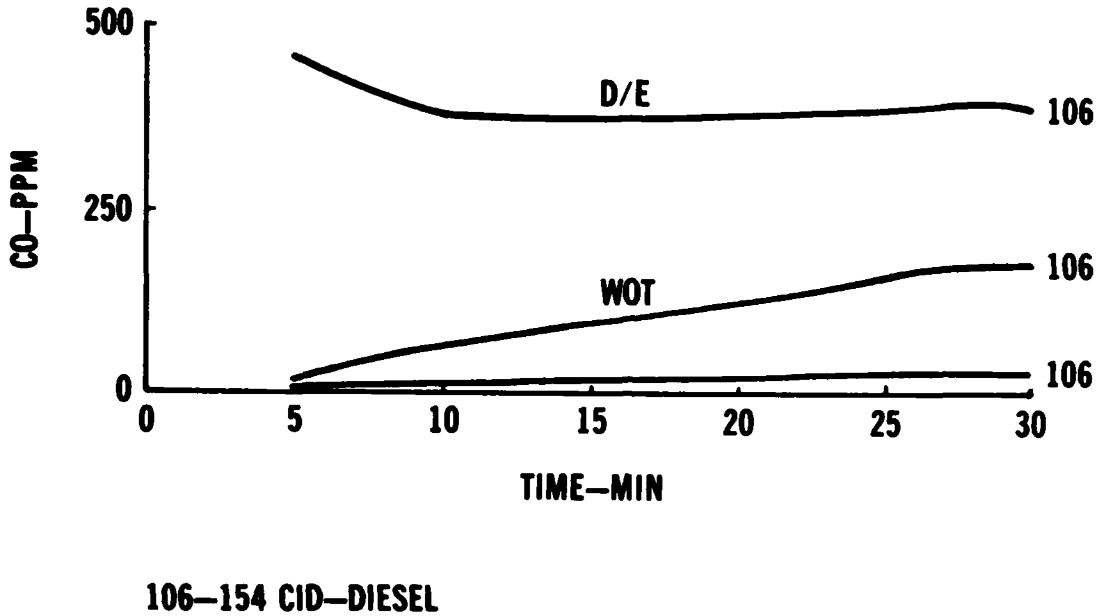


Figure D12. Average—room sample and direct exhaust.

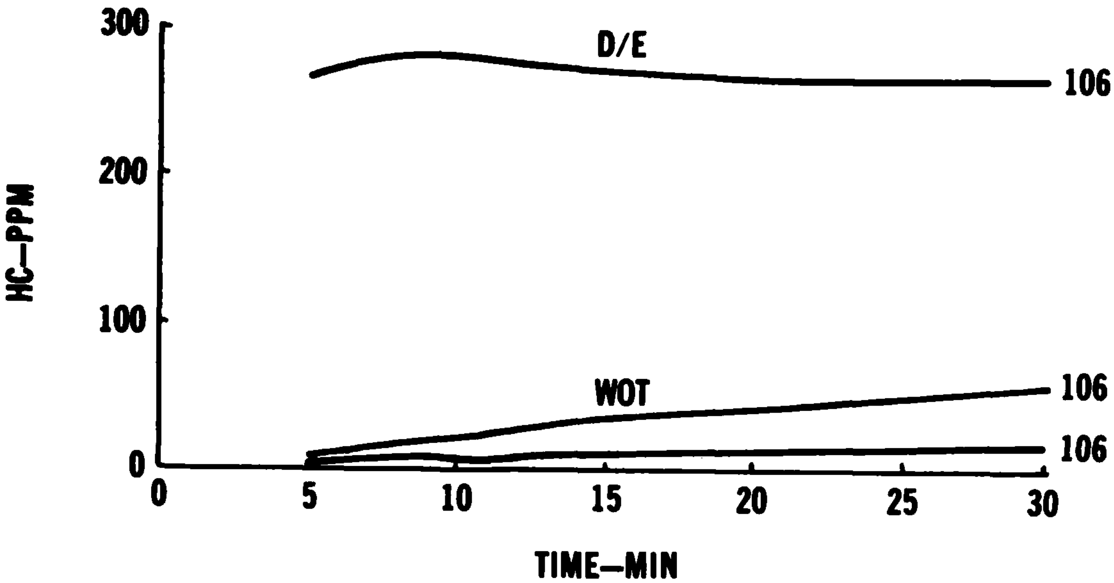


Figure D13. Average—room sample and direct exhaust.

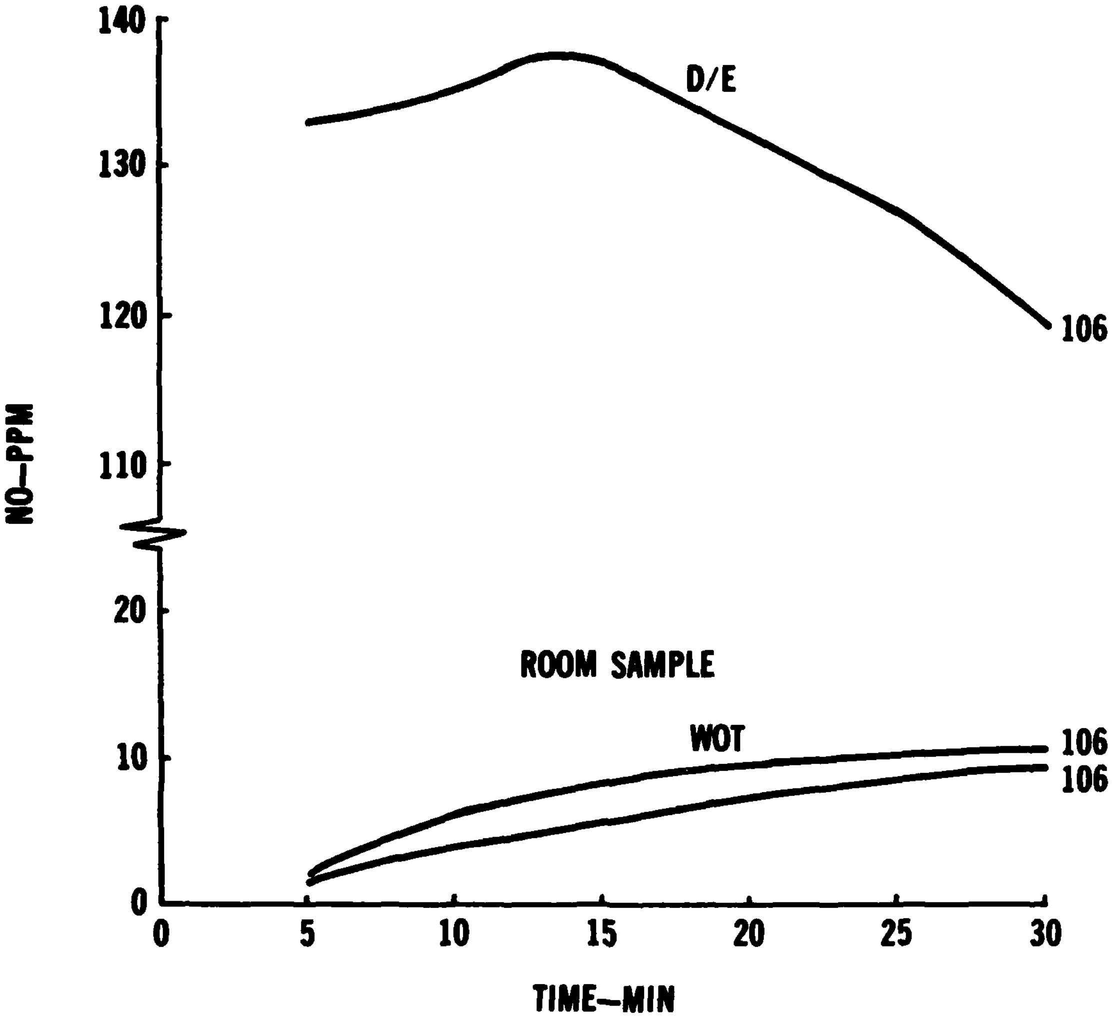


Figure D14. Average—room sample and direct exhaust.

All test results for any particular vehicle were not expected to be the same. It was believed however, that if all emission test conditions were repeated as nearly identical as possible, any change from one test to another would be due to the wear of the engine during use.

A comparison of some of the idle and wide-open throttle (WOT) graphs may seem to give results that are not expected. This is due to the fact that engine exhaust emissions are effected by variables such as engine temperature and air-fuel ratio which change from idle to WOT and the engine may even be running more efficiently at the faster speed. An example of this can be seen on the Average HC graphs for Truck No. 92 (Figure D4) which shows the test cell level of HC to be about 400 ppm after 30 min at idle while at WOT, the average level after 30 min is under 300 ppm (Figure D5).

The graph of average direct exhaust idle HC emissions for Truck No. 92 and No. 94 (Figure D6) indicates that HC emission from Truck No. 94 decreases from the cold start-up and approaches a steady-state value as the engine runs. The curve for Truck No. 92 (Figure D6) shows that HC also decreases from start-up, although not as much as Truck No. 94, and reaches a steady-state value which is very close to the initial value. The average room sample idle curves for these trucks (Figure D4) show that the room environment level of HC increases much faster with Truck No. 94 than for Truck No. 92.

The average CO and HC graphs for Trucks No. 91 and No. 95 (Figure D4 through D9) generally show that the curves are so close together that a comparison between these two LPG trucks results in no distinct difference. One exception to this is the average direct exhaust idle NO graph which shows Truck No. 95 to be higher than No. 91 (Figure D11).

A comparison between Truck No. 92 and Truck No. 94 (gasoline powered) for CO on the curves for average direct exhaust idle (Figure D9) indicates that Truck No. 92 (162 in.^{3}) emits about 10 percent more CO than Truck No. 94 (135 in.^{3}) and that the emission level is fairly constant over the 30-min test for each truck. The CO curves for average room sample idle for Truck No. 92 and Truck No. 94 (Figure D7) show that the test cell environment accumulated more CO with Truck No. 92 than Truck No. 94.

The average graphs for CO and HC (Figures D4 through D9) clearly show that the LPG-powered trucks (Nos. 91 and 95) emit lower levels of CO and HC than the gasoline-powered trucks (Nos. 92 and 94) at idle and wide-open throttle. The graphs generally show the curves for Truck Nos. 94 and 92 grouped together and the curves for Truck Nos. 91 and 95 grouped together. An exception to this is the curve for Truck No. 92 on the HC-WOT graph (Figure D5) which is very close to the LPG trucks. This indicates that unburned fuel (HC) for Truck No. 92 at WOT is much lower than for No. 94. The average graphs for NO (Figures D10 through D11) indicate that the LPG trucks emit more NO at idle and wide-open throttle than the gasoline-powered trucks except that Truck No. 94 produces a high level of NO at WOT.

The average graphs for CO (Direct Exhaust-Idle) indicate that Truck No. 106 (diesel) emits about 50 percent of the CO emitted by the LPG trucks and about 12 percent of the CO emitted by the gasoline trucks at idle (Figure D12). The average graphs for HC (Direct Exhaust-Idle) indicate that Truck No. 106 (diesel) emits about 12 to 18 percent of the HC emitted by the LPG trucks and about 3 percent of the HC emitted by the gasoline trucks at idle (Figure D13). The average NO graphs (Direct Exhaust-Idle) indicate that Truck No. 106 emits about 300 percent to 1000 percent of that emitted by the gasoline trucks and about 30 to 50 percent of the NO emitted by the LPG trucks (Figure D14).

It should be noted that 30 min of engine idling by Truck No. 106 (diesel), Truck No. 91 (LPG), or No. 95 (LGP) in the closed test cell does not cause the environment to exceed a CO level of 50 ppm (Figures D7 and D12). A CO level of 50 ppm is the accepted limit for a safe working environment for air contaminants (Table D1). The gasoline powered trucks, at idle, cause the environment in the cell to exceed 50 ppm CO almost immediately (Figure D7). In actual use, the working volume would be larger than the test cell and would not be totally sealed which would extend the working time. These values, however, illustrate that the diesel engine compares favorably with the LPG engines for emission of CO. Table D2 is a summary of the steady-state emission values for readings of the test-room environment and readings at the engine exhaust. A review of these emission values from the different engines under the same conditions illustrates the favorable emission aspects of the LPG engines and diesel engines as compared with the gasoline engines.

The level or concentration of the contaminants in the direct exhaust sample of the engines that were measured does not allow for the difference in actual flow rate of exhaust emitted from the different engines. Although the forklift trucks tested are all of similar size, their engine displacements varied and different exhaust volumetric flow rates would be expected for the same rpm. This would explain some of the difference observed on Table D1 in cases where the direct exhaust valves are similar and yet there is a difference noted for the room environment level for two engines of different displacements.

A smoke test was attempted for the diesel engine powered forklift truck. Since the emission tests were done under no load conditions, there was very little evidence of smoke emission, both by instrumentation and visual inspection. This diesel engine would emit some smoke for a short period during the first start of the day and under heavy load, but at idle and light or no load, little smoke was evident.

The graphs for each forklift truck taken from emission tests performed at intervals do not indicate a consistent change over time between tests for any of the emissions measured. This could be because the hours put on the engine between the tests were not enough to make a significant difference or that the variables that were not controlled that affect emissions had more effect than any change in the engine due to use.

Table D2. Test Results (Average Emissions — PPM)***

Truck	LPG		Gasoline		Diesel
	No. 91	No. 95	No. 92	No. 94	No. 106
*HC-WOT	170	187	283	1726	58
*HC-IDLE	80	81	384	775	16
*CO-WOT	142	372	968	981	178
*CO-IDLE	39	19	1475	1258	29
*NO-WOT	46	37	21	53	10
*NO-IDLE	8	10	2	2	9
**HC	1521	2405	9151	8212	265
**CO	815	841	3481	3122	384
**NO	247	376	44	12	119

* Emission level after 30 min in closed room of 7500 ft^3 (WOT = wide open throttle at governed speed).

** Value after 30 min (hot engine) — Direct Exhaust — Idle (Sample probe inserted in exhaust-engine at idle).

*** Parts per million (Emission average of 4 tests for all engines).

NOTE: Truck No. 91 and No. 92 had 162 $in.^3d$ 4-cylinder engines. Truck No. 94 and No. 95 had 135 $in.^3d$ 4-cylinder engines. Truck No. 106 had a 154 $in.^3d$ 4-cylinder diesel engine. The diesel fuel used conforms to Fed Spec VV-F-800C for Grade DF-2 except that the particulate contamination exceeded the specified limit by 1.6 mg/l.

5. **Conclusions.**

a. The LPG-powered test truck engines emit significantly less HC and CO than the gasoline-powered test truck engines.

b. The LPG-powered test truck engines emit more NO than the gasoline test truck engines.

c. No progressive change in emissions was observed for any of the test trucks over time from the start of the test to 280 engine h.

d. The 162 $in.^3$ gasoline-powered engine (No. 92) produces more emissions (HC, CO, NO) at idle than the 135 $in.^3$ gasoline-powered engine (No. 94). For LPG at idle, there is little difference between the two engines for emission of CO, but the smaller engine (135 $in.^3$, No. 95) produces more HC and NO than the larger engine (162 $in.^3$, No. 91).

e. Truck No. 106 (diesel) emits significantly less HC than the LPG- or gasoline-powered trucks.

f. Truck No. 106 (diesel) emits more NO than the gasoline-powered trucks but less than the LPG-powered trucks.

g. The direct-exhaust sample for truck No. 106 (diesel) shows significantly less CO than the gasoline- or LPG-powered trucks.

APPENDIX E

COMPILED TEST RESULTS OF EVALUATING LIFT TRUCKS NO. 91(A), NO. 92(B), NO. 94(C), NO. 95(D), NO. 103(E), AND NO. 106(F) ON COURSE A (MIL-STD-268C), COURSE C (CONCRETE), AND COURSE G (GRAVEL)

Key

Courses:

A = 200 Hour

C = Concrete

G = Gravel

Trucks:

A = No. 91 (LPG–Commercial–162 in.^{3})

B = No. 92 (Gasoline–Commercial–162 in.^{3})

C = No. 94 (Gasoline–Military–135 in.^{3})

D = No. 95 (LPG–Converted–Military–135 in.^{3})

E = No. 103 (Electric–Commercial)

F = No. 106 (Diesel–Commercial–154 in.^{3})

VEHICLE-A COURSE-A **Truck No. 91**

CYCLE TIME (s)

N= 3178 MEAN= 197.164 DEVIATION= 23.248

PRODUCTIVITY (CYCLES/h)

N= 249 MEAN= 16.460 DEVIATION= 3.488

CYCLES/ENGINE h

N= 90 MEAN= 16.393 DEVIATION= 1.738

FUEL (CYCLES/UNIT OF FUEL)

N= 55 MEAN= 2.354 DEVIATION= .268

VEHICLE-B COURSE-A **Truck No. 92**

CYCLE TIME (s)

N= 2842 MEAN= 210.861 DEVIATION= 39.430

PRODUCTIVITY (CYCLES/h)

N= 205 MEAN= 16.060 DEVIATION= 5.995

CYCLES/ENGINE h

N= 95 MEAN= 14.993 DEVIATION= 2.873

FUEL (CYCLES/UNIT OF FUEL)

N= 42 MEAN= 3.110 DEVIATION= .688

VEHICLE-C COURSE-A **Truck No. 94**

CYCLE TIME (s)

N= 3330 MEAN= 214.123 DEVIATION= 28.545

PRODUCTIVITY (CYCLES/h)

N= 209 MEAN= 15.554 DEVIATION= 2.668

CYCLES/ENGINE h

N= 91 MEAN= 16.709 DEVIATION= 2.996

FUEL (CYCLES/UNIT OF FUEL)

N= 42 MEAN= 2.983 DEVIATION= .700

VEHICLE-D COURSE-A **Truck No. 95**

CYCLE TIME (s)

N= 3085 MEAN= 207.237 DEVIATION= 40.389

PRODUCTIVITY (CYCLES/h)

N= 258 MEAN= 15.902 DEVIATION= 3.305

CYCLES/ENGINE h

N= 85 MEAN= 15.572 DEVIATION= 1.773

FUEL (CYCLES/UNIT OF FUEL)

N= 59 MEAN= 2.013 DEVIATION= .278

VEHICLE-E COURSE-A **Truck No. 103**

CYCLE TIME (s)

N= 2791 MEAN= 231.729 DEVIATION= 29.269

PRODUCTIVITY (CYCLES/h)

N= 180 MEAN= 13.481 DEVIATION= 3.069

CYCLES/ENGINE h

N= 80 MEAN= 14.526 DEVIATION= 1.800

FUEL (CYCLES/UNIT OF FUEL)

N= 60 MEAN= 1.513 DEVIATION= .694

VEHICLE-F COURSE-A **Truck No. 106**

CYCLE TIME (s)

N= 3822 MEAN= 183.260 DEVIATION= 20.998

PRODUCTIVITY (CYCLES/h)

N= 205 MEAN= 18.560 DEVIATION= 2.744

CYCLES/ENGINE h

N= 40 MEAN= 19.048 DEVIATION= 3.340

FUEL (CYCLES/UNIT OF FUEL)

N= 33 MEAN= 5.557 DEVIATION= .344

Vehicle: 91
Test Course: Concrete

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
A	C	05-21-80	60		001		0725	0755	31.7		L
A	C	05-21-80	60	6.25	002	17	0756	0815		32.5	G
A	C	05-21-80	64		003		0820		32.5		L
A	C	05-21-80	64		004			0900			G
A	C	05-21-80	64		005		0920	1115			J
A	C	05-21-80	64	28.75	006	90	1220	1355		36.5	J
A	C	05-21-80	63		007		1400		36.5		L
A	C	05-21-80	63		008	30	0715	1515	37.7	37.7	G
A	C	05-21-80	63	28.75	009	56		0955		40.3	
A	C	01-21-81	39		010		0800		252.8		E
A	C	01-21-81	39	10.00	011	39		1030		254.9	E
A	C	01-21-81	40		012	15	1330	1400	254.9	256.7	E
A	C	01-21-81	40		013	15	1405	1500	256.7	257.6	E
A	C	01-22-81			014	20	0920	1015	257.6	258.7	E
A	C	01-22-81		27.00	015	18	1030	1115	258.7	259.6	E
A	C	01-22-81			016	16	1230	1306	259.6	260.5	E
A	C	01-22-81			017	14	1330	1400	260.5	261.6	E
A	C	01-23-81			018	23	0900	1050	261.6	262.6	E
A	C	01-23-81		30.00	019	39	1240	1415	262.6	264.3	E
A	C	01-28-81	43		020	43	1215	1400	271.7	273.5	E
A	C	01-28-81	43		021	17	1425	1530	273.5	274.6	E
A	C	01-29-81	43		022	19	0845	0920	274.6	275.4	E
A	C	01-29-81	43	29.00	023	11	0940	1005	275.4	275.8	E
A	C	01-29-81	43		024	19	1030	1115	275.8	276.6	E
A	C	01-29-81	43		025	25	1235	1350	276.6	277.9	E
A	C	01-29-81	43		026	20	1355	1400	277.9	278.9	G
A	C	01-29-81	43	30.76	027	28	1405	1515	278.9	280.2	E
A	C	02-02-81			028	10	0830	0850	280.2	280.6	E
A	C	02-02-81			029	18	0915	1006	280.6	281.4	G
A	C	02-02-81			030	12	1011	1115	281.4	282.2	E
A	C	02-02-81			031	10	1315	1347	282.2	283.1	S
A	C	02-02-81			032	10	1400	1446	282.7	283.1	E
A	C	02-03-81	24		033	10	0815	0845	283.1	283.5	S
A	C	02-03-81	24	28.50	034	3	0848	0905	283.5	283.7	E
A	C	02-03-81	31		035	10	1400	1510	283.7	284.1	E
A	C	02-04-81	16		036	60	1245	1500	284.1	286.9	E
A	C	02-05-81	14	32.50	037	15	0745	0826	286.9	287.7	E
A	C	02-05-81	14		038	21	0900	1000	287.7	288.7	E
A	C	02-05-81	14		039	20	1000	1100	288.7	289.7	E
A	C	02-05-81	14	26.25	040	35	1245	1335	289.7	291.3	E

Energy Consumed: 277.75 Cycles Completed: 808 Elapsed Engine Hours: 39.7

Materials Handling Equipment Power Source Evaluation

Vehicle: 91
Test Course: Gravel

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
A	G	12-10-80	40		001	20	1325	1440	220.2	221.4	E
A	G	12-10-80	40		002	6	0750		221.4	221.8	G
A	G	12-10-80	40	26.00	003	35		1500	221.8	224.4	E
A	G	12-12-80	41		004	30			224.4	226.3	E
A	G	12-12-80	41		005	17			226.3		E
A	G	12-12-80	41	30.00	006	34				229.3	L
A	G	12-15-80	34		007	20	0755	0905	229.3	232.2	E
A	G	12-15-80	34		008	10	1320	1400	232.2	234.1	L
A	G	12-15-80	34		009	10	1420	1500	234.1	234.7	E
A	G	12-15-80	34	27.50	010	30	1230	1330	234.7	235.9	E
A	G	12-16-80	35		011	15	1320		235.9	236.7	L
A	G	12-16-80	35		012	20		1515	236.7	237.7	E
A	G	12-16-80	35		013	15	0745		237.7	238.6	E
A	G	12-16-80	35		014	15			238.6	239.4	E
A	G	12-16-80	35	29.25	015	7			239.4	239.7	E
A	G	12-19-80	45		016	25			239.7	241.0	E
A	G	12-19-80	45		017	20			241.0	242.4	S
A	G	12-19-80	45	26.25	018	33			242.0	242.9	E
A	G	12-22-80			019	20			242.9	244.0	E
A	G	12-22-80			020	21			244.0	244.7	S
A	G	12-22-80		25.00	021	27			244.7	245.8	E
A	G	01-16-81			022	20			245.8	246.8	E
A	G	01-16-81			023	20			246.8	248.1	S
A	G	01-16-81		30.00	024	31			248.1	250.6	E
A	G	01-19-81			025	10			250.6	251.4	E
A	G	01-19-81		12.50	026	20			251.4	252.8	E
A	G	01-23-81	38		027	25	0900	1005	264.3	265.7	E
A	G	01-23-81	38		028	25	1030	1130	265.7	267.0	L
A	G	01-23-81	38	29.50	029	21	1230	1325	267.0	268.1	E
A	G	01-27-81	52		030	22	1400	1510	268.1	269.1	E
A	G	01-27-81	52		031	16	0800	0840	269.1	269.9	E
A	G	01-27-81	52	27.25	032	34	0915	1125	269.9	271.7	E

Energy Consumed: 263.25 Cycles Completed: 674 Elapsed Engine Hours: 40.0

Materials Handling Equipment Power Source Evaluation

Vehicle: 92
Test Course: Concrete

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
B	C	10-25-79	42		001	20	0745	0900	25.3	26.5	C
B	C	10-25-79	42		002	14	0926	1013	26.5	27.3	C
B	C	10-25-79	42		003	17	1027	1119	27.3	28.15	C
B	C	10-25-79	42	19.145	004	7	1227	1250	28.15	28.7	C
B	C	10-26-79	38	6.750	005	16	0800	0850	28.75	29.65	C
B	C	10-29-79	64		006	15	0943	1027	29.85	30.6	L
B	C	10-29-79	64		007	15	1027	1115	30.6	31.4	J
B	C	10-29-79	64		008	2	1115	1121	31.4	31.5	L
B	C	10-29-79	64		009	9	1225	1428	31.5	33.7	J
B	C	10-29-79	64	22.725	010	46	1438	1508	33.7	34.2	J
B	C	10-30-79	55		011	19	0742	0855	34.3	35.4	J
B	C	10-30-79	55		012	35	0922	1119	35.5	37.25	J
B	C	10-30-79	55		013	16	1225	1320	37.25	38.2	J
B	C	10-30-79	55	24.685	014	12	1430	1512	39.1	39.75	J
B	C	10-31-79	52		015	29	0715	0855	39.15	41.4	J
B	C	10-31-79	52		016	52	0920	1122	41.4	43.55	C
B	C	10-31-79	52	22.509	017	111	1225	1513	43.55	46.1	J
B	C	11-01-79	56	11.771	018	32	0830	1030	46.2	47.8	
B	C	11-19-79		14.725	019	64	0930	1520	48.9	53.3	
B	C	11-20-79	60	21.025	020	75	0715	1515	53.5	59.3	
B	C	11-21-79	57	24.805	021	96	0735	1425	59.3	65.3	
B	C	11-23-79	55	11.380	022	52	0720	1100	65.3	68.5	

Energy Consumed: 179.52 Cycles Completed: 754 Elapsed Engine Hours: 38.8

Materials Handling Equipment Power Source Evaluation

Vehicle: 92
Test Course: Gravel

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
B	G	08-08-80	80		001	4	0950	1030	276.1	276.8	S
B	G	08-08-80	80		002	25	0840	1050	277.7	279.7	S
B	G	08-08-80	80		003	6	1100	1130	279.7	280.2	E
B	G	08-08-80	80		004	19	1230	1404	280.2	281.6	S
B	G	08-08-80	80	19.605	005	13	1405	1450	281.6	282.4	L
B	G	08-11-80	83		006	10	0749	0840	281.6	283.3	S
B	G	08-11-80	83		007	15	0903	1015	283.3	284.5	S
B	G	08-11-80	83		008	18	1018	1125	284.5	285.5	E
B	G	08-11-80	83		009	17	1325	1220	285.5	286.5	L
B	G	08-11-80	83		010	10	1330	1417	286.5	287.3	S
B	G	08-11-80	83	18.325	011	10	1420	1440	287.3	287.9	E
B	G	08-12-80	84		012	20	0710	0830	287.9	289.2	E
B	G	08-12-80	84		013	22	0845	1000	289.2	290.5	E
B	G	08-12-80	84		014	13	1030	1125	290.5	291.2	E
B	G	08-12-80	84		015	11	1234	1320	291.2	291.8	L
B	G	08-12-80	84	18.925	016	19	1320	1420	291.8	292.9	E
B	G	08-13-80	76		017	30	0645	0830	292.9	294.5	E
B	G	08-13-80	76		018	30	0900	1115	294.5	296.0	E
B	G	08-13-80	76		019	20	1230	1325	296.0	297.1	E
B	G	08-13-80	76		020	17	1335	1430	297.1	298.0	E
B	G	08-13-80	76		021	26	0700	0817	298.0	299.4	E
B	G	08-13-80	76		022	27	0830	0950	299.4	300.8	L
B	G	08-13-80	76	38.150	023	13	0955	1100	300.8	301.8	S
B	G	08-14-80	79		024	30	1105	1124	301.8	302.1	S
B	G	08-14-80	79		025	19	1230	1330	302.1	302.2	L
B	G	08-14-80	79		026	23	1330	1430	302.2	304.5	E
B	G	08-14-80	79	16.505	027	26	0640	0815	304.5	306.0	E

Energy Consumed: 111.51 Cycles Completed: 493 Elapsed Engine Hours: 29.8

Vehicle: 94
Test Course: Concrete

					Seq.	No.	Cycle Time		Engine Hours		
V	C	Date	T	Fuel	No.	Cyc.	Start	Stop	Start	Stop	D
C	C	03-14-80	38		001		0920		138.9		J
C	C	03-14-80	38	20.628	002	33		1115		140.8	D
C	C	03-17-80	50		003		0725		140.8		G
C	C	03-17-80	50		004			0900			G
C	C	03-17-80	50		005		0925				L
C	C	03-17-80	50		006	40		1045		142.8	L
C	C	03-17-80	50		007		1045		142.8		G
C	C	03-17-80	50		008			1120			G
C	C	03-17-80	50		009		1230	1355			L
C	C	03-17-80	50		010		1420	1515		145.3	L
C	C	03-17-80	50		011		0730		145.3		G
C	C	03-17-80	50	22.125	012	83		0835		146.3	L
C	C	03-19-80	57		013		1035		146.4		
C	C	03-19-80	57		014			1115			
C	C	03-19-80	57		015		1220				
C	C	03-19-80	57	22.170	016	52		1500		148.9	
C	C	03-21-80	58		017		0750		152.9		D
C	C	03-21-80	58		018			0900			J
C	C	03-21-80	58		019		0920				J
C	C	03-21-80	58		020			1115			J
C	C	03-21-80	58		021		1245				J
C	C	03-21-80	58	25.738	022	95		1510		157.1	J
C	C	04-09-80			023		0730	0905	175.8		G
C	C	04-09-80			024		0925	1100			L
C	C	04-09-80		19.625	025	75	1220	1235		179.1	J
C	C	05-20-80	45		026		0745	0900	133.9		
C	C	05-20-80	45		027		0920	1120			
C	C	05-20-80	45		028		1220	1400			
C	C	05-20-80	45	21.950	029	70	1420	1515		138.2	
C	C	08-06-80			030	14	1030	1130	90.2	90.9	E
C	C	08-06-80			031	35	1230	1445	90.9	93.0	E
C	C	08-06-80		17.125	032	31	0645	0845	93.0	94.8	E
C	C	08-07-80			033	30	0900	1115	94.8	96.5	E
C	C	08-07-80		11.700	034	28	1215	1350	96.5	98.0	E

Energy Consumed: 161.061 Cycles Completed: 586 Elapsed Engine Hours: 29.5

Vehicle: 94
Test Course: Gravel

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
C	G	04-04-80	55		001		0800		168.5		L
C	G	04-04-80	55		002		1115				G
C	G	04-04-80	55		003	42	1220				J
C	G	04-04-80	55		004			1345		172.7	J
C	G	04-04-80	55		005		1350		172.7		J
C	G	04-04-80	55	22.035	006	41		1505		173.4	J
C	G	07-24-80	77		007	13	1242	1330	50.1	50.9	L
C	G	07-24-80	77		008	13	1332	1450	50.9	52.2	E
C	G	07-24-80	77		009	10	1245	1355	52.2	53.2	E
C	G	07-24-80	77		010	65	1335	1450	53.2	54.5	S
C	G	07-24-80	77	16.925	011	13	0700	0750	54.5	55.4	E
C	G	07-29-80	82		012	23	0756	0840	55.5	56.2	S
C	G	07-29-80	82		013	10	0850	0935	56.2	56.8	W
C	G	07-29-80	82		014		0951	1005	56.8		L
C	G	07-29-80	82		015	10	1010	1050		57.8	S
C	G	07-29-80	82		016	8	1055	1130	57.8	58.4	E
C	G	07-29-80	82		017	14	1230	1335	58.4	59.4	E
C	G	07-29-80	82	16.725	018	20	1350	1445	59.4	60.4	L
C	G	07-30-80	78		019	20	0730	0910	60.4	61.9	E
C	G	07-30-80	78		020	30	0925	1120	61.9	63.8	E
C	G	07-30-80	78	18.925	021	23	1300	1445	63.8	65.5	E
C	G	07-31-80	72		022	17	0700	0730	65.5	66.1	E
C	G	07-31-80	72		023	10	0735	0820	66.1	66.8	E
C	G	07-31-80	72		024	32	0830	1040	66.8	68.9	L
C	G	07-31-80	72		025	12	1040	1125	68.9	69.8	L
C	G	07-31-80	72		026	14	1230	1330	69.8	70.7	E
C	G	07-31-80	72	17.545	027	11	1330	1450	70.7	71.8	L
C	G	08-01-80	78		028	20	0650	0826	71.8	73.5	S
C	G	08-01-80	78		029	20	0850	1015	73.5	74.9	W
C	G	08-01-80	78		030	20	1020	1138	74.9	76.3	S
C	G	08-01-80	78		031	22	1220	1350	76.3	77.8	E
C	G	08-01-80	78	20.725	032	3	1350	1400	77.3	78.0	S
C	G	08-04-80	73		033	40	0700	1000	78.0	80.9	E
C	G	08-04-80	73		034	7	1015	1110	80.9	81.4	E
C	G	08-04-80	73		035	30	1215	1350	81.4	82.7	E
C	G	08-04-80	73		036	5	1400	1430	82.7	83.0	E
C	G	08-04-80	73	18.925	037	13	0630	0730	83.0	83.8	E
C	G	08-05-80	78		038	40	0815	1100	83.8	86.4	E
C	G	08-05-80	78		039	10	1230	1315	86.4	87.0	E
C	G	08-05-80	78		040	20	1330	1445	87.0	88.2	E
C	G	08-05-80	78		041	13	0700	0815	88.2	89.3	E
C	G	08-05-80	78	18.925	042	14	0845	0950	89.3	90.2	E

Energy Consumed: 150.73 Cycles Completed: 728 Elapsed Engine Hours: 45.4

Vehicle: 95
Test Course: Concrete

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
D	C	10-09-80	70		001	16	0915	1014	125.1	126.3	S
D	C	10-09-80	70		002	16	1016	1115	126.3	127.3	L
D	C	10-09-80	70		003	16	1225	1322	127.3	128.2	S
D	C	10-09-80	70	26.25	004	29	1326	1505	128.2	129.8	L
D	C	12-16-80	40		005	16	1340		214.9	215.5	S
D	C	12-16-80	40	11.00	006	15		1515	215.5	216.1	E
D	C	12-17-80	28		007	6	0730		216.1	216.4	G
D	C	12-17-80	28		008	14			216.4	217.6	S
D	C	12-17-80	28		009	15			217.6	218.5	G
D	C	12-17-80	28		010	15			218.5	219.1	S
D	C	12-17-80	28	30.25	011	20		1300	219.1	220.0	G
D	C	12-17-80	40		012	24	1300		220.0	221.0	J
D	C	12-17-80	40		013	21		1515	221.0	222.0	G
D	C	12-17-80	40	26.50	014	17	0745	1030	222.0	222.8	S
D	C	12-19-80	46		015	10	1045	1115	222.8	223.3	S
D	C	12-19-80	46		016	25	1245		223.3	224.5	S
D	C	12-19-80	46		017	10	1015		224.9	225.4	S
D	C	12-19-80	46	26.75	018	10		1130		225.4	G
D	C	01-16-81	35		019	1	1230		225.4	225.9	L
D	C	01-16-81	35		020	44		1450	225.9	228.1	G
D	C	01-16-81	35	22.50	021	3	0945		228.1	229.0	S
D	C	01-19-81	38		022	20	0750		229.0	229.9	S
D	C	01-19-81	38		023	20			229.9	230.8	S
D	C	01-19-81	38	18.75	024	11		1500	230.8	231.3	S
D	C	01-21-81			025	20	1330		231.3	232.6	G
D	C	01-21-81			026	20			232.6	233.7	S
D	C	01-21-81		30.00	027	9		1510	233.7	234.1	G
D	C	01-22-81	30		028	20	0920	1025	234.1	235.5	S
D	C	01-22-81	30		029	10	1040	1115	235.5	235.9	S
D	C	01-22-81	30	27.25	030	26	1310	1515	235.9	237.0	S
D	C	01-23-81	38		031	20	0745	0850	237.0	238.2	S
D	C	01-23-81	38		032	10	0915	0945	238.2	238.7	S
D	C	01-23-81	38		033	10	1000	1030	238.7	239.1	S
D	C	01-23-81	38	24.00	034	11	1130	1235	239.1	239.7	S
D	C	01-23-81	38		035	20	1300	1405	239.7	240.6	S
D	C	01-23-81	38		036	10	1430	1515	240.6	241.0	S
D	C	01-23-81	38	24.75	037	13	1250	1345	241.0	241.3	S
D	C	01-26-81	48		038	19	1405	1515	242.3	243.2	G
D	C	01-26-81	48	24.75	039	42	0950	1115	243.3	245.2	S
D	C	01-27-81	52		040	35	1220	1515	245.2	246.7	S
D	C	01-27-81	52	31.00	041	35	0800	0930	246.7	248.3	S
D	C	01-28-81	36		042	36	1230	1335	248.3	249.3	S
D	C	01-28-81	36		043	36	1425	1515	249.3	249.9	S
D	C	01-28-81	36		044	36	0800	0910	249.9	251.1	S
D	C	01-28-81	36	31.00	045	36	1000	1120	251.1	251.5	S

Energy Consumed: 354.75 Cycles Completed: 868 Elapsed Engine Hours: 39.8

Vehicle: 95
Test Course: Gravel

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
D	G	01-29-81	43		001	10	1220	1310	251.5	252.6	S
D	G	02-04-81	16	32.75	002	30	1245	1430	252.6	255.7	S
D	G	02-04-81	26		003	7	1440	1500	255.7	256.1	S
D	G	02-05-81	14		004	13	0745	0830	256.1	257.0	S
D	G	02-05-81	14		005	15	0915	1025	257.0	257.8	S
D	G	02-05-81	14	29.25	006	15	1040	1120	257.8	258.6	S
D	G	02-05-81	18		007	15	1245	1350	258.6	259.6	S
D	G	02-05-81	18		008	10	1355	1440	259.6	261.3	E
D	G	02-05-81	18		009	10	1445	1520	261.3	261.8	S
D	G	02-09-81	18	27.25	010	11	0730	0835	261.8	262.6	S
D	G	02-09-81	23		011	15	0845	0945	262.6	263.6	E
D	G	02-09-81	23		012	15	0950	1030	263.6	264.3	S
D	G	02-09-81	23		013	10	1035	1115	264.3	264.8	E
D	G	02-09-81	23		014	10	1230	1315	264.8	265.4	S
D	G	02-09-81	23		015	10	1320	1410	265.4	265.9	E
D	G	02-09-81	23		016	20	1415	1500	265.9	266.9	S
D	G	02-10-81	28	37.00	017	7	0730	0800	266.9	267.4	E
D	G	02-10-81	28		018	10	0815	0925	267.4	268.4	S
D	G	02-10-81	28		019	10	0930	1000	268.4	268.9	E
D	G	02-10-81	28		020	10	1005	1030	268.9	269.4	S
D	G	02-10-81	28		021	19	1035	1130	269.4	270.4	E
D	G	02-10-81	28	24.25	022	11	1230	1315	270.4	271.1	S
D	G	02-10-81	28		023	18	1320	1410	271.1	272.1	E
D	G	02-10-81	28		024	12	1425	1510	272.1	272.8	S
D	G	02-13-81	17		025	20	0800	0905	272.8	274.3	L
D	G	02-13-81	17		026	20	0910	1045	274.3	275.5	S
D	G	02-13-81	17	29.25	027	2	1050	1100	275.5	275.6	L
D	G	02-13-81	29		028	12	1105	1130	275.6	276.0	L
D	G	02-13-81	29		029	18	1230	1345	276.0	277.2	S
D	G	02-13-81	29		030	20	1405	1520	277.2	278.2	S
D	G	02-17-81	49	27.25	031	13	0810	0920	278.2	279.1	S
D	G	02-17-81	49		032	20	0930	1044	279.1	280.2	E
D	G	02-17-81	49		033	15	1045	1130	280.2	281.0	S
D	G	02-17-81	49	23.00	034	20	1230	1340	281.0	282.0	E
D	G	02-18-81	45		035	20	0745	0855	282.0	283.4	S
D	G	02-18-81	45		036	20	0900	1000	283.4	284.5	E
D	G	02-18-81	45		037	1	1010	1015	284.5	284.5	W
D	G	02-18-81	45		038	19	1245	1405	284.5	285.7	S
D	G	02-18-81	45	29.75	039	16	1415	1500	285.7	286.5	E
D	G	02-19-81	51		040	20	0715	0900	286.5	288.0	S
D	G	02-19-81	51		041	10	0930	1000	288.0	288.7	W
D	G	02-19-81	51		042	23	1002	1115	288.7	290.0	E
D	G	02-19-81	51	30.50	043	18	1210	1310	290.0	290.0	S
D	G	02-19-81	51	4.50	044	10	1315		290.9	291.5	E

Energy Consumed: 294.75 **Cycles Completed: 630** **Elapsed Engine Hours: 40.0**

Materials Handling Equipment Power Source Evaluation

Vehicle: 103
Test Course: Concrete

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
E	C	02-29-80	25		001		0930	1115	95.5		
E	C	02-29-80	25	41	002	50	1220	1545		98.5	
E	C	03-05-80	44		003		1055	1115	100.5		
E	C	03-05-30	44		004	48	1220	1500		102.9	
E	C	03-06-80	43		005		0915	1115	102.9		
E	C	03-06-80	43	27	006	50	1220	1300		105.5	
E	C	03-13-80	30		007		0730	0900	121.6		
E	C	03-13-80	30		008		0930	1115			
E	C	03-13-80	30		009	70	1220	1500		125.5	
E	C	03-14-80	33	40	010	18	0700	0815	125.5	126.6	
E	C	04-23-80	48		011		0625	0900	176.8		
E	C	04-23-80	48		012		0920	1130			
E	C	04-23-80	48	48	013	107	1215	1245		183.0	
E	C	04-23-80	50		014		1440	1545	183.0	184.3	
E	C	04-28-80	50		015		0720	0900	184.3		
E	C	04-28-80	50		016		0920	1120			
E	C	04-28-80	50	93	017	93	1215	1245		188.2	
E	C	06-18-80	76	47	018	24	0945	1120	243.7	246.2	
E	C	06-18-80	76	43	019	23	0945	1110	246.4	248.0	
E	C	08-14-80	69		020	15	0710	0810	310.8		
E	C	08-14-80	69	30	021	25	0848	1035		313.6	

Energy Consumed: 369 Cycles Completed: 523 Elapsed Engine Hours: 31.3

Materials Handling Equipment Power Source Evaluation

Vehicle: 103
Test Course: Gravel

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
E	G	05-10-80	66		001	1	0815		189.1		S
E	G	05-10-80	66		002	39		1140		192.5	S
E	G	05-10-80	66		003	1	1240		192.5		S
E	G	05-10-80	66	54	004	9		1338		193.5	S
E	G	05-10-80	66		005	1	1422		193.5		S
E	G	05-10-80	66	6	006	13		1540		194.7	S
E	G	06-02-80	70		007	30	0915	1120	209.9		
E	G	06-02-80	70		008	25	1340	1445		214.8	
E	G	06-02-80	70		009	15	0640		214.8		
E	G	06-02-80	70	26	010	20		0800		216.1	
E	G	06-03-80	75		011	4	0840	0855	216.2	216.5	D
E	G	06-03-80	75		012	17	0940	1125	216.5	217.6	D
E	G	06-03-80	75		013	19	1230	1400	217.6	219.0	D
E	G	06-04-80	79	48	014	20	1000	1130	219.0	220.3	D
E	G	06-04-80	79		015	10	1315	1355	220.3	221.0	D
E	G	06-05-80	75		016	36	0635	0900	221.0	223.3	
E	G	06-05-80	75		017	14	0920	1025	223.3	224.2	
E	G	06-05-80	75	55	018	10	1045	1125	224.2	224.9	
E	G	06-05-80	75		019	20	1315	1435	225.0	226.4	
E	G	06-06-80	66		020	33	0640	0855	226.4	228.5	
E	G	06-06-80	66	27	021	7	0920	0955	228.5	229.0	
E	G	06-06-80	66		022	20	1005	1125	229.0	230.3	
E	G	06-06-80	66		023	20	1220	1345	230.3	231.7	
E	G	06-07-80	68		024	20	0620	0745	231.7	233.1	
E	G	06-07-80	68	29	025	10	0815	0900	233.1	233.8	
E	G	06-07-80	84		026	30	0935	1110	233.8	235.3	D
E	G	06-07-80	84		027	20	1205	1300	235.8	236.4	D
E	G	06-07-80	84		028	10	1300	1430	236.4	237.2	D
E	G	06-07-80	84	37	029	10	1435	1510	237.2	237.8	D
E	G	06-17-80	58		030	30	0758	1030	238.0	239.0	D
E	G	06-17-80	58		031	15	1032	1122	239.0	241.0	L
E	G	06-17-80	58		032	20	1230	1330	241.0	242.0	L
E	G	06-17-80	58	46	033	15	1330	1430	242.0	243.2	D
E	G	06-18-80	68	47	034	21	0800	0930	243.2	244.7	D

Energy Consumed: 375 Cycles Completed: 585 Elapsed Engine Hours: 38.5

Vehicle: Diesel
Test Course: Concrete

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
F	C	08-03-81	80		001	20	0955	1110	221.2	222.3	W
F	C	08-03-81	80		002	5	1110	1127	222.3	222.9	L
F	C	08-03-81	80		003	15	1220	1300	222.9	223.1	L
F	C	08-03-81	80		004	20	1302	1408	223.1	224.2	B
F	C	08-03-81	80	13.00	005	20	1410		224.2	225.0	L
F	C	08-04-81	73		006	20	0705	0815	225.0	226.1	B
F	C	08-04-81	73		007	20	0818	0910	226.1	227.0	L
F	C	08-04-81	73		008	20	0911	0915	227.0	228.1	W
F	C	08-04-81	73	12.00	009	23	0916	1115	228.1	229.1	L
F	C	08-05-81	87		010	20	0853	1000	229.3	230.1	E
F	C	08-05-81	87		011	20	1001	1055	230.1	231.0	B
F	C	08-05-81	87		012	10	1057	1121	231.0	231.4	E
F	C	08-05-81	87		013	10	1230	1300	231.4	231.8	E
F	C	08-05-81	87		014	30	1300	1425	231.8	233.2	B
F	C	08-05-81	87	13.725	015	15	1426	1500	233.2	233.8	E
F	C	08-06-81	70		016	40	0700	0905	233.8	235.7	B
F	C	08-06-81	70		017	9	0906	0933	235.7	236.2	W
F	C	08-06-81	70		018	31	0933	1105	236.2	237.7	B
F	C	08-06-81	70		019	20	1220	1320	237.7	238.6	B
F	C	08-06-81	70	21.925	020	15	1325	1430	238.6	239.5	G
F	C	08-07-81	64		021	20	0700	0800	239.5	240.5	B
F	C	08-07-81	64		022	20	0802	0850	240.5	241.2	L
F	C	08-07-81	64		023	20	0851	0951	241.2	242.7	B
F	C	08-07-81	64		024	12	0952	1045	242.7	243.2	L
F	C	08-07-81	64		025	20	1047	1150	243.2	244.3	B
F	C	08-07-81	64	14.875	026	11	1220	1250	244.3	244.9	L
F	C	08-18-81	60		027	22	0700	0806	245.5	246.6	B
F	C	08-18-81	60		028	23	0809	0910	246.6	247.6	S
F	C	08-18-81	60		029	20	0913	1015	247.6	248.7	B
F	C	08-18-81	60		030	20	1018	1120	248.7	249.6	S
F	C	08-18-81	60		031	20	1215	1318	249.6	250.6	B
F	C	08-18-81	60		032	20	1325	1415	250.6	251.5	S
F	C	08-18-81	60	20.425	033	15	1417	1500	251.5	252.1	B
F	C	08-19-81	64		034	20	0715	0815	252.1	253.1	B
F	C	08-19-81	64		035	20	0817	0910	253.1	254.0	S
F	C	08-19-81	64		036	20	0912	1010	254.0	254.9	B
F	C	08-19-81	64		037	20	1012	1105	254.9	255.8	S
F	C	08-19-81	64		038	5	1107	1125	255.8	256.1	B
F	C	08-19-81	64		039	15	1224	1310	256.1	256.8	B
F	C	08-19-81	64		040	20	1314	1407	256.8	257.7	S
F	C	08-19-81	64	19.925	041	20	1408	1503	257.7	258.6	B
F	C	08-20-81	58		042	20	0705	0820	258.6	259.6	B
F	C	08-20-81	58		043	20	0822	0915	259.6	260.5	S
F	C	08-20-81	58		044	20	0917	1015	260.5	261.4	B
F	C	08-20-81	58	10.00	045	16	1018	1114	261.4	262.2	S

Energy Consumed: 125.875 Cycles Completed: 842 Elapsed Engine Hours: 40.4

Materials Handling Equipment Power Source Evaluation

Vehicle: Diesel
Test Course: Gravel

V	C	Date	T	Fuel	Seq. No.	No. Cyc.	Cycle Time Start	Cycle Time Stop	Engine Hours Start	Engine Hours Stop	D
F	G	08-21-81	79	1.000	001	20	1300	1410	262.2	263.4	E
F	G	08-24-81	76		002	20	0730	0825	263.4	264.3	E
F	G	08-24-81	76		003	20	0829	0932	264.3	265.4	S
F	G	08-24-81	76		004	20	0935	1040	265.4	266.5	E
F	G	08-24-81	76		005	20	1217	1322	266.5	267.5	S
F	G	08-24-81	76		006	20	1325	1430	267.5	268.5	E
F	G	08-24-81	76	14.000	007	20	1432	1527	268.5	269.4	S
F	G	08-25-81	72		008	20	0755	0906	269.4	270.7	G
F	G	08-25-81	72		009	20	0907	1009	270.7	271.7	E
F	G	08-25-81	72		010	20	1011	1114	271.7	272.7	G
F	G	08-25-81	72		011	20	1200	1300	272.7	273.7	E
F	G	08-25-81	72		012	20	1300	1404	273.7	274.8	W
F	G	08-25-81	72	13.925	013	20	1414	1515	274.8	275.8	G
F	G	08-26-81	75		014	20	0720	0826	275.8	277.0	G
F	G	08-26-81	75		015	20	0827	0935	277.0	278.0	E
F	G	08-26-81	75		016	20	0940	1041	278.0	279.0	S
F	G	08-26-81	75		017	18	1043	1130	279.0	279.9	G
F	G	08-26-81	75		018	22	1215	1335	279.9	281.0	E
F	G	08-26-81	75	13.425	019	20	1340	1445	281.0	282.3	G
F	G	08-27-81	64		020	20	0700	0805	282.3	283.3	E
F	G	08-27-81	64		021	20	0810	0917	283.3	284.4	G
F	G	08-27-81	64		022	20	0918	1024	283.4	285.5	E
F	G	08-27-81	64		023	20	1025	1122	285.5	286.5	G
F	G	08-27-81	64		024	20	1125	1233	286.5	287.5	E
F	G	08-27-81	64		025	20	1235	1340	287.5	288.5	W
F	G	08-27-81	64	14.925	026	16	1342	1425	288.5	289.4	G
F	G	08-28-81	65		027	20	0710	0715	289.4	290.5	G
F	G	08-28-81	65		028	20	0816	0920	290.5	291.5	E
F	G	08-28-81	65		029	20	0920	1024	291.5	292.6	G
F	G	08-28-81	65		030	20	1025	1130	292.6	293.6	E
F	G	08-28-81	65		031	20	1130	1228	293.6	294.5	W
F	G	08-28-81	65		032	20	1234	1333	294.5	295.5	G
F	G	08-28-81	65	15.025	033	14	1345	1420	295.5	296.2	E
F	G	08-31-81	70		034	20	0705	0810	296.2	297.3	G
F	G	08-31-81	70		035	20	0811	0915	297.3	298.4	E
F	G	08-31-81	70		036	20	0919	1020	298.4	299.4	G
F	G	08-31-81	70		037	20	1025	1130	299.4	300.5	E
F	G	08-31-81	70		038	20	1217	1319	300.5	301.5	G
F	G	08-31-81	70	12.125	039	12	1320	1400	301.5	302.2	E

Energy Consumed: 84.425 Cycles Completed: 762 Elapsed Engine Hours: 41.0

APPENDIX F

RELIABILITY, AVAILABILITY, MAINTAINABILITY DATA SUMMARY

FROM FORKLIFT POWER SOURCE EVALUATION

MAINTAINABILITY

EASE OF MAINTENANCE STUDY

Test Item: ACC-45 FLT No. 92 | Date: 16 August 1979

Submitted by: HP Mullins | Mechanic: Jacob Davis

Type Maintenance	# men	hours	min	manhours
1. Remove, replace and adjust all engine driven belts.	1		8	.13
2. Remove and replace alternator.	1		15	.25
3. Remove and replace regulator.	N/A		N/A	N/A
4. Remove and replace all filters, screens and strainers in hydraulic system.	1		30	.50
5. Remove and replace coolant system hoses.	1		50	.83
6. Drain engine lubricating oil, remove and replace oil filter elements, and refill.	1		15	.25
7. Remove and replace fuel filter elements.	1		5	.08
8. Disconnect battery cables, remove and replace batteries, and reconnect cables.	1		10	.16
9. Drain torque converter oil and transmission oil, remove and replace all filter elements and strainers and refill converter and transmission.	1		35	.58
10. Remove and replace starter.	1		25	.41
11. Bleed and adjust brakes and refill master cylinder.	1		20	.33

Remarks: Operator's seat/engine cover opened but not removed.

MAINTAINABILITY

EASE OF MAINTENANCE STUDY

Test Item: ACC 40PA FLT No. 94 Date: 15 August 1979

Submitted by: HP Mullins Mechanic: Jacob Davis

Type Maintenance	# men	hours	min	manhours
1. Remove, replace and adjust all engine driven belts.	1		7	.12
2. Remove and replace alternator.	1		20	.33
3. Remove and replace regulator.	N/A		N/A	N/A
4. Remove and replace all filters, screens and strainers in hydraulic system.	1		40	.66
5. Remove and replace coolant system hoses.	1		60	1.00
6. Drain engine lubricating oil, remove and replace oil filter elements, and refill.	1		20	.33
7. Remove and replace fuel filter elements.				
8. Disconnect battery cables, remove and replace batteries, and reconnect cables.	1		15	.25
9. Drain torque converter oil and transmission oil, remove and replace all filter elements and strainers and refill converter and transmission.	1		45	.75
10. Remove and replace starter.	1		30	.50
11. Bleed and adjust brakes and refill master cylinder.	1		20	.33

Remarks: Operator's seat and engine compartment cover was removed to gain access to engine compartment.

MAINTAINABILITY

EASE OF MAINTENANCE STUDY

Test Item: ACE-45 FLT No. 103 (electric)   Date: 22 January 1982

Submitted by: Aubrey Thomas Jr.   Mechanic: Jacob Davis

Type Maintenance	# men	hours	min	manhours
1. Remove & replace drive motor brushes.	1		7:25	0.124
2. Remove & replace hoist & tilt motor brushes.	1		6:38	0.110
3. Remove & replace steer motor brushes.	1		5:17	0.088
4. Remove & replace all contactor tips.	1		8:40	0.144
5. Remove & replace all filters, screens & strainers in hydraulic system.	1		8:23	0.140
6. Bleed & adjust brakes and refill master cylinder.		N/A fluid		
7. Remove & replace battery.	2		2:00	0.066
8. Remove & replace circuit boards in controller.	1		9:46	0.163
9. Remove & replace all fuses.	1		2:34	0.043

Remarks: (1) Remove top panel .... 5:00 = 0.083

(2) Remove bottom panel .... 3:53 = 0.065

MAINTAINABILITY

EASE OF MAINTENANCE STUDY

Test Item: S40E FLT No. 96 Date: 8 January 1979

Submitted by: H.W. Lawrence Mechanic: Jacob Davis

Type Maintenance	# men	hours	min	manhours
1. Remove, replace and adjust all engine driven belts.	1		50	.83
2. Remove and replace alternator.	1		50	.83
3. Remove and replace regulator.	N/A		N/A	N/A
4. Remove and replace all filters, screens and strainers in hydraulic system.	1		10	.16
5. Remove and replace coolant system hoses.	1		45	.75
6. Drain engine lubricating oil, remove and replace oil filter elements, and refill.	1		30	.50
7. Remove and replace fuel filter elements.	1		4	.07
8. Disconnect battery cables, remove and replace batteries, and reconnect cables.	1		15	.25
9. Drain torque converter oil and transmission oil, remove and replace all filter elements and strainers and refill converter and transmission.	1		75	1.25
10. Remove and replace starter.	1		60	1.00
11. Bleed and adjust brakes and refill master cylinder.	1		30	.50

Remarks: Regulator is built into alternator.
See notes on attached sheet.

1. It was necessary to move air intake assembly in order to remove hydraulic filter.

2. After changing fuel filters, it was required to bleed fuel system by loosening fitting at each injector and at filter input to restart engine. This took 18 min which was not included on study sheet.

3. Battery removal was difficult because the transmission dipstick tube is too close, and also more "cutout" of frame is needed to make it easier. Replacing the battery was less difficult and it was assumed that the replacement battery was serviced and ready. (No time was recorded for adding acid or charging the new battery.)

4. To service truck, we had to put it on blocks using a larger fork truck and the shop overhead crane. This was more difficult since no lifting eyes were on the truck. *This took about 1 h.* A pit or special floor lift is needed.

5. To remove starter the first section of exhaust pipe had to be removed.

Table F1. No. 91 Allis-Chalmers LPG (Commercial) Forklift Truck

EPR No.	Date	Engine Hrs	Securing Decision		Maintenance		Power Pack	Incident Description
			Step	Classification	Diagnostic	Repair	Related	
91-1	23 Apr 80	22.0	11	UM&SF	1.5	4.0	No	RAM cylinder replaced.
91-2	23 Apr 80	22.0			0.1	1.5	No	Replaced crossover tube assembly as precautionary on one.
91-3	30 May 80	66.7	11	UM&SF	0.75	1.0	Yes	Clogged fuel filter.
91-4	2 June 80	73.0	11	UM&SF	0.1	1.0	No	Tire failed.
91-5	13 June 80	88.0	11	UM&SF	0.25	0.5	Yes	Fuel lock filter
91-6	14 June 80	88.9	11	UM&SF	0.25	0.5	No	Capscrew
91-7	23 June 80	98.0	11	UM&SF	1.0	6.0	No	Roller bearing in mast
91-8	24 June 80	100.0	11	UM&SF	0.1	0.75	No	Interlock adjusted.
91-9	21 July 80	117.5	11	UM&SF	0.1	0.5	No	Hydraulic leak—replace O-ring.
91-10	21 July 80	117.5	11	UM&SF	.25	1.75	No	Universal joint

Table F2. No. 92 Allis-Chalmers Gasoline (Commercial) Forklift Truck

EPR No.	Date	Engine Hrs	Securing Decision Step	Securing Decision Classification	Maintenance Diagnostic	Maintenance Repair	Power Pack Related	Incident Description
92-8		11	4					
92-3	4 Oct 79	9.7	10	UM&SF			No	Capscrew
92-3A	4 Oct 79	22.1	10	UM	0	0.25	No	Capscrew
92-2	12 Oct 79	23.8	11	UM&MF	0.1	0.75	No	Crossover tube assembly
92-1	31 Oct 79	39.7	10	UM	0.1	0.25	No	Capscrew
92-2A	1 Nov 79	47.8	11	UM&SF	0.1	2.5	No	Crossover tube assembly
92-5	27 Nov 79	80.2	11	UM&SF	0.1	0.4	No	
92-4	28 Nov 79	82.4	11	UM&SF	0.5	1.5	No	Brake lines
92-6	10 Dec 79	98.0	11	UM&SF	0.5	1.5	No	Master cylinder
92-7	12 Dec 79	102.0	11	UM&SF	0.25	2.5	No	Brakes
92-2B	17 Mar 80	113.8	11	UM&SF	0.2	1.5	No	Hydraulics—crossover tube assembly
92-3B	9 Mar 80	115.8	11	UM&SF	0.2	0.75	No	Lift cylinder—capscrews
92-2C	22 Apr 80	124.6	11	UM&SF	0.2	1.5	No	Hydraulics—crossover tube assembly
92-2D	2 May 80	144.2	11	UM&SF	0.2	1.5	No	Hydraulics—crossover tube assembly
92-8	2 June 80	165.3	11	UM&SF	0.75	2.0	No	Brake linings

Table F3. No. 94 Allis-Chalmers Gasoline (Military) Forklift Truck

EPR No.	Date	Engine Hrs	Securing Decision Step	Securing Decision Classification	Maintenance Diagnostic	Maintenance Repair	Power Pack Related	Incident Description
94-2	31 Oct 79	62.1	11	UM&SF	0.25	0.5	No	Capscrew
94-1	1 Nov 79	64.5	11	UM&SF	0.25	0.5	Yes	Spark plug failure
94-1A	1 Nov 79	64.5		UM	0.10	0.25	Yes	Adjusted points
94-1B	1 Nov 79	64.5		UM	0.00	0.25	Yes	Engine compression check
94-1C	5 Nov 79	73.5	11	UM&SF	0.5	0.25	Yes	Engine misfire—spark plug
94-3	5 Nov 79	75.3	11	UM&SF	0.15	0.3	Yes	Vacuum leak
94-4	8 Nov 79	91.7	10	UM	0.10	0.15	No	Lift cylinder screw loose
94-5	8 Nov 79	93.4	9	UM	0.10		No	Radiator grill screws
94-6	14 Feb 80	133.3	11	UM&SF	0.10	0.5	No	Adjusted crossover tube assembly.
94-7	19 Feb 80	142.8	11	UM&SF	0.1	0.5	No	Yoke pin missing.
94-6A	28 Mar 80	167.3	11	UM&SF	0.1	1.0	No	Adjusted crossover tube assembly.
94-6B	11 Apr 80	181.2	11	UM&SF			No	Modified crossover tube assembly.
94-8	3 May 80	189.4	11	UM&SF	3.0	4.0	Yes	Engine
94-6C	7 May 80	199.0	11	UM&SF	0.2	0.75	No	Adjusted crossover tube assembly.
94-9	9 May 80	206.3	9	UM	0.3	0.3	Yes	Engine hourmeter ran slow.
94-6D	10 May 80	211.8	11	UM&SF	0.5	1.5	No	Crossover tube assembly

Table F4. No. 95 Allis-Chalmers LPG-Converted (Military) Forklift Truck

			Securing Decision		Maintenance		Power Pack	
EPR No.	Date	Engine Hrs	Step	Classification	Diagnostic	Repair	Related	Incident Description
95-1	3 May 80	9.9	9	UM	0.1	0.5	No	Panel hourmeter
95-2	9 June 80	25.7	10	UM	0.1	0.3	Yes	Cooling system
95-3	11 June 80	33.8	11	UM&SF	0.25	0.5	No	Bleed hydraulic system
95-4	17 June 80	58.4	10	UM	0.2	0.3	Yes	Cooling system, pipe had to be tightened.
95-5	19 June 80	70.8	11	UM&SF	0.5	0.5	Yes	Fuel lock filter
95-6	4 Aug 80	78.6	11	UM&SF	0.5	0.75	Yes	Fuel filter
95-7	2 Oct 80	125.1	11	UM&SF	0.5	0.75	No	Broken brake lining.

Table F5. No. 103 Allis-Chalmers Electric (Commercial) Forklift Truck

			Securing Decision		Maintenance		Power Pack	
EPR No.	Date	Engine Hrs	Step	Classification	Diagnostic	Repair	Related	Incident Description
103-1	31 Oct 79	4.7	11	UM&SF	0.2	0.5	No	Hydraulic leak O-ring replaced.
103-2	7 Nov 79	8.0	11	UM&SF	0.25	1.25	Yes	Replaced fuse 400-amp main power.
103-3	30 Nov 79	27.4		UM&SF	0.5	1.5	No	Hydraulic leaks
103-5	10 Dec 79	37.0	10	UM	0.0	0.25	No	Interlock assembly out of adjustment.
103-3A	11 Dec 79	38.0	11	UM&SF	0.75	0.75	No	Hydraulic leaks-replaced O-ring.
103-5A	13 Dec 79	43.8	10	UM	0.0	0.25	No	Interlock assembly out of adjustment.
103-4	14 Dec 79	49.0	11	UM&SF	0.25	1.75	No	Crossover tubes—hydraulic tube
103-4A	9 Jan 80	52.0	11	UM&SF	0.5	1.75	No	Cross tubes—misalignment.
103-2A	23 Jan 80	85.0	11	UM&SF	0.25	0.75	Yes	Replaced fuse contactor.
103-5	24 Jan 80	86.3	11	UM&SF	4.0	12.0	Yes	Motor coil
103-4B	14 Mar 80	126.7	11	UM&SF	0.25	1.75	No	Leaks at crossover assembly
103-4C	19 Mar 80	132.0	11	UM&SF	0.25	1.75	No	Leaks at crossover misaligned.
103-4D	24 Mar 80	135.8	11	UM&SF	0.25	1.75	No	Leaks at lift cylinder
103-4E	11 Apr 80	167.0	11	UM&SF	0.25	1.75	No	Leaks at lift cylinder
103-5	17 Apr 80	176.4	11	UM&SF	1.0	3.0	No	Roller retainers
103-5A	13 May 80	224.9	11	UM&SF	0.5	3.0	Yes	Hydraulic pump motor

Table F6. No. 106 Hyster Diesel (Commercial) Forklift Truck

EPR No.	Date	Engine Hrs	Securing Decision		Maintenance		Power Pack	Incident Description
			Step	Classification	Diagnostic	Repair	Related	
96-1	17 Apr 81	38.4	3	No Test			No	Shims front-load roller system
96-2	5 June 81	129.0	11	UM&SF	0.0	0.25	No	Tire separated from rim.
96-3	23 July 81	194.6	11	UM&SF	0.0	0.25	No	Tire separated from rim.
96-4	4 Aug 81	229.1	11	UM&SF	0.0	0.25	No	Left front tire separated.

APPENDIX G

PETROLEUM PRODUCTS LABORATORY ANALYSIS REPORT,

DA FORM 2077

PETROLEUM PRODUCTS LABORATORY ANALYSIS REPORT

For use of this form, see TM 10-1105; the proponent agency is U.S. Continental Army Command

SAMPLE NO.	HMW
LAB REPORT NO.	02039CHMY
PRODUCT NOMENCLATURE AND TYPE	DIESEL FUEL SAMPLE
SPEC NO.	VV-F-800
SAMPLE SUBMITTED BY *(Installation)*	DRDME-HW
AMT PROD SAMPLE REPRESENTS	
MANUFACTURER OR SUPPLIER OF PRODUCT	
SOURCE OF SAMPLE *(Truck, Tank, Aircraft, etc.)*	
SAMPLE TAKEN BY *(Name)*	
CONTRACT NO.	
ITEM NO.	
FSN	
DATE SAMPLE TAKEN	
QUAL NO.	
BATCH NO.	
FILL DATE	
DLVR DATE	
DATE SAMPLE REC	
NAME AND LOCATION OF LABORATORY	
DATE TESTS STARTED	
DATE TESTS COMPL	

- [ ] FUEL BULK STORAGE
- [ ] FUEL PACKAGED
- [ ] ALLIED PRODUCTS
- [ ] FILTER EFFECTIVENESS
- [ ] QUALIFICATION CONTRACT
- [ ] ROUTINE SURVEILLANCE
- [ ] PROCUREMENT ORIGIN
- [ ] PROCUREMENT
- [x] SPECIAL
- [ ] DEPOT

TEST	SPEC/QUAL	RESULT	TEST	SPEC/QUAL	RESULT
1. GRAVITY °API/SP GR 60°/60°F TOP		33.75	27. WATER AND SEDIMENT % VOL MAX		
a. 73°F .845 MID			28. FSII % VOL TOP		
b. RPT .555 BOT			a. MID		
c. AVG			b. BOT		
2. APPEARANCE/WORKMANSHIP			c. AVG		
3. COLOR VISUAL			29. PARTICULATE CONTAMINANT MGS/L	10	11.6
a. HELLIGE *(Colorimeter)*			30. THERMAL STABILITY INCHES HG		
b. ASTM MAX/SAYB MIN			a. PREHEATER RATING		
c. SAYB AFTER HEAT MIN			31. SULFIDES *(Tank Water BTMS)*		
4. ODOR			32. WATER SEPAROMETER INDEX MIN		
5. DISTILLATION IBP °F		365	33. % ASH PLAIN/SULF MAX		
a. 10 % REC - EVAP AT °F		431	34. % LEAD		
b. 20 % REC - EVAP AT °F		454	35. % PHOSPHORUS		
c. 50 % REC - EVAP AT °F		513	36. % CHLORINE		
d. 90 % REC - EVAP AT °F	640 max	617	37. BURNING TEST *(16 hrs)*		
e. FBP/DRY PT °F	698 max	634	38. KIN CS/SSU AT °F		
f. % RECOVERED		94	a. KIN CS/SSU AT °F		
g. % LOSS		2.2	b. KIN CS/SSU AT °F		
h. % RESIDUE	3 max	3.8	c. KIN CS/SSU AT °F		
i. 10% + 50% EVAP °F MIN			d. SSF AT °F		
6. ENGINE RATING O.N. MOTOR METHOD			e. VISCOSITY INDEX MIN		
a. ON RESEARCH METHOD			39. EVAP LOSS % MAX		
b. LMR AVIATION METHOD			40. PRECIPITATION NO MAX		
c. RMR SUPER CH METHOD		49.81	41. SEPARATION % MAX		
d. CETANE NUMBER/INDEX MIN	45		42. ACID NO/BASE NO MAX		
7. RVP *(PSI)*			43. CHANNEL PT °F MAX		
8. GUM EXISTENT MG/100 ML MAX			44. SAPONIFICATION NO MAX		
GUM *(Wash)* MG/100 ML MAX			45. DIELECTRIC STRENGTH KV MIN		
GUM POTENTIAL MG/100 ML MAX			46. FOAM SEQ 1. MLS MAX *(TND/STAB)*		
PRECIPITATE MG/100 ML MAX			a. SEQ 2. MLS MAX *(TND/STAB)*		
9. TEL/TML *(ML/GM/GAL)* MAX			b. SEQ 3. MLS MAX *(TND/STAB)*		
10. OXIDATION STABILITY MINUTES			47. PENETRATION UNWORKED 77°F		
11. DR TEST/MERC S % MAX			a. PENETRATION WORKED 77°F		
12. SULFUR BY LAMP BOMB % MAX Leco		.17	48. DROP PT/MELT PT °F MIN		
13. FREEZING PT °F			49. CORR AND OXIDATION STAB		
14. CORROSION COPPER STRIP			50. SWELLING SYN RUBBER %		
15. AROMATICS % VOL MAX			51. LOW TEMP STABILITY		
16. OLEFINS % VOL MAX			52. SALT SPRAY TEST		
17. SMOKE POINT MM MIN			53. WORK STABILITY		
18. SMOKE VOLAT INDEX MIN			54. WATER STABILITY		
19. ANILINE PT °F/ANILINE GRAV PROD MIN			55. THICKENER TYPE		
20. FLASH/FIRE POINT °F MIN	56	73.3	56. THICKENER CONTENT %		
21. CLOUD POINT °F MAX	-3	-27°F	57. CORROSION PROTECTION		
22. POUR POINT °F MAX			58. REMOVAL		
23. WATER REACT INTERFACE RATING MAX			59. APPARENT VISC AT °F		
a. VOLUME CHANGE MAX			a. SHEAR RATE POISES		
24. CARBON RESIDUE % WT MAX			60. SED CONTAM. MILLIPORE, MG/L. MAX		
25. WATER % VOL MAX			61. EFFECTIVENESS OF FILTRATION		
26. SEDIMENT % VOL MAX			62. OTHER *(Specify)*		

REMARKS

FAILURE PARTICULATE CONTAMINATION

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